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AGRICULTURE

IN SOME OF ITS RELATIONS WITH

CHEMISTRY

BY

F. H. STORER, S.B., A.M.

PROFESSOR OF AGRICULTURAL CHEMISTRY IN HARVARD UNIVERSITY

IN TWO VOLUMES

VOL. II.

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AGRICULTURE.

CHAPTER I.

COMPOSTS.

In discussing methods of preserving farmyard manure, as in the last chapter of the first volume, the question of compost-making naturally presents itself, and attention is called forcibly to the consideration of several well-known facts which bear upon this subject.

It is a matter of old observation, that, if some kinds of peat be mixed with fresh stable manure in the proportion of two or three loads of the peat to one load of the dung, and the mixture be then allowed to ferment, there will be obtained a compound as efficient, load for load, for many fertilizing purposes, as pure stable manure. The observation has often been verified in this country, as well as in Europe, and cannot be gainsaid. Doubtless several causes conspire to produce this result. The fertilizing qualities proper to the peat are utilized, and the fermentation which it undergoes conduces to this end. The power of the peat to absorb and hold water comes into play also. But there is still ample room left for the argument that, owing to the presence of the peat in the mixture, the stable manure has fermented to better advantage than it would have done by itself. This thought not only bears directly upon the question of preparing composts with dung, but, as has already been suggested, it is most intimately connected with the problem how best to preserve manures.

Composting saves Manure.

As matters actually stand, there appears to be little doubt that the results of practical experience teach that, in many situations, a larger proportion of the useful ingredients of dung and urine can be saved by mixing these substances with comparatively large quantities of peat, or loam, or clay, or straw, before fermentation has set in, than by suffering the manure to ferment in the barnyard by itself. But in such admixture may be seen the beginnings of the so-called process of composting, and it may be said, truly enough, that composting is practised in some sort wherever loam and peat, or even straw, are used for bedding animals.

It may be well at this point to recur to the practical experience of farmers, and to cite some new examples from it, though it needs to be said, at the start, that many farmers have strongly objected to the use of loam bedding in cow stables. Their objections are based, however, mainly upon the dirtiness of the earth and the labor of handling it; they do not depend upon chemical considerations, and most farmers seem to agree that cow manure may be very well preserved by the earth. Some farmers have claimed, indeed, that cows can be kept clean enough for all practical purposes by using straw for bedding them, in conjunction with the loam; and they hold that the trouble thus taken is more than paid for by the comfort of the animals and the increase of manure. Probably peat or loam covered with sawdust would serve a good purpose.

Loam for bedding Animals.

Rotenhan, in Germany, describes as follows his method of bedding 100 head of neat cattle during the winter months on nothing but loam. A line of heavy joists is laid down and firmly fastened to the floor behind the animals, i. e. between them and the gangway, in order to hold the loam in place. The whole of the standing-room between these joists and the cribs is filled with a layer of dry loam, the depth of which is as much as 8 or 10 inches at the rear, i. e. next the joist. In this way a horizontal layer of earth is provided for the animals to stand upon.

Three or four times a day the dung, with whatever loam has become moistened with urine, is scraped out and left in little heaps behind the animals, while the holes and irregularities of surface that have been made by removing the loam are filled up or smoothed off by scraping into them earth from other parts of the bed. Once a day the heaps of dung and loam are thrown out into the yard. At the end of every fortnight or three weeks, the standing-room is cleaned out and a new layer of loam laid down in it, for the reason that the continual trampling of the cattle impacts the earth so firmly that it can no longer absorb urine as quickly as is desired.

In order that the animals may be kept clean, dry, and healthy in this way, it is essential that the earth should be dry. Sandy loam does well, and so do loams rich in humus, but clays are bad. The more humus there is in the earth, so much the larger will its power of absorbing water be, and so much the smaller quantity of it will be required. The use of dry peat for this purpose is not uncommon. Rotenhan carted the loam in autumn and kept it under a roof. Each of his animals appears to have used as much as one or two two-horse loads of the loam every month. Heiden computes that, for 1000 lb. of live weight, cows will need some 180 lb. of loam (2½ cubic feet) per diem in order that they may stand tolerably dry.

Another way of applying the earth is cited by Professor Johnson in his essay on "Peat and its Uses." Mr. Holbrook of Brattleboro', Vt., every morning before cleaning the cow stable, throws a bushel-basketful of peat upon the dung behind each of the animals. The peat absorbs completely the urine and other moisture of the manure, which is held in a water-tight trench behind the animals, and the warm mixture soon enters into fermentation when thrown from the stable. Mr. Holbrook, looking at the matter as a making of manure from peat rather than as a saving of manure by peat, maintains that "much more peat can be well prepared for use in the spring in this way, than by any of the ordinary methods of composting."

Compost Heaps.

Many farmers prefer to make their compost in heaps. A common plan is to lay down a bed of peat six or eight feet wide and a foot or so thick, to cover it with a layer of dung of somewhat less thickness, followed by another layer of peat, and so on, until the heap has become three or four feet high. Various proportions of peat are employed by different farmers in the preparation of these compost heaps. The ordinary range is from 1 to 5 loads of peat to 1 load of manure, according to the kind of peat and the quality of the dung. Rich dung from stall-fed horses or fatting cattle will bear more peat than that from animals less highly fed. If there be much straw or other litter in the manure, less peat will be added to it than if the dung were clear. Besides, the farmer would naturally tend to use more or less peat in composting, according as his land is light and sandy and in need of humus, or already charged with that substance.

The practical rule is, to use no more peat "than can be thoroughly fermented by the manure," though it may perhaps be fairly questioned whether this rule is well founded. Possibly a better rule would be, not to use enough peat or other admixture wholly to prevent the dung from fermenting.

In case the dung were free from long litter, it is possible, though not probable, that it might be still better to mix as much peat with the dung as will just prevent it from fermenting. But, in our ignorance of what the so-called process of fermentation is, it would be hard to determine which of the three rules is theoretically the best. If we could only be sure, when peat enough is used to prevent the dung from fermenting in the usual way, that the heap would not proceed to ferment in some other unusual and hurtful way, and so destroy itself, the subject would be a good deal clearer than it is now. Probably there are many cases where it would be well to keep dung and urine in the barnyard fresh and raw, if that could be done without too much labor, even if the peat should remain unfermented. Whether this could ever be done without risk, and, if so, when and how, are points still to be studied. The probabilities are that it would not be very easy to do it unless the mixture were put in a silo. Hence the second rule suggested, not to use enough peat wholly to prevent the dung from fermenting, may possibly be the best of the three.

Practically, the amount of peat to be used must always be determined by considerations of economy relating to the particular farm on which the compost is to be made. So long as peat can be hauled at small cost by men and teams belonging to the farm, at times when work is slack, and no more profitable way of expending the labor can be found, it will be well to haul it, provided that the cost of labor to be expended in preparing the compost and in distributing the bulky material in the fields is less than the cost of obtaining an equivalent quantity of commercial fertilizers would be.

Composts require much Labor.

As regards weight and the amount of water which it can hold in its pores, swamp muck differs less from farmyard manure than might be supposed. As tested by Henry Stewart, a cubic foot of soft wet muck, such as could be cut like butter, although it was somewhat fibrous, weighed, as taken from the bog, 67 lb. When dried in warm air, it gave off 83% of water. At the same time, Stewart found that fresh horse manure, free from litter, when pressed

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tightly into a box with a rammer, weighed 64 lb. to the cubic foot; and that fresh cow manure, free from litter, and similarly packed, weighed 66½ lb. to the cubic foot. Cow manure taken from the bottom of a heap, where it was saturated with urine and had become partly rotted, weighed 70½ lb. to the cubic foot.

On the other hand, it must always be remembered, that the commercial fertilizers are concentrated and compact, and that the cost of distributing them is small. It is true, in fact, that the widely extended use of these fertilizers in recent years, or rather the ability to procure them readily, has caused composts to fall into disrepute. Compost heaps are established much more rarely nowadays in New England than they were formerly; though the remark, as quoted by Professor Johnson, that "the composting of muck and peat with stable and barnyard manures is surely destined to become one of the most important items in farm management throughout all the older States," is probably still true of a land of small proprietors, for whose labor there is at times no profitable outgo. It can hardly be accepted, however, as it stands, with regard to farms worked by hired labor for the sake of money profit only. In the immediate vicinity of a city, moreover, it would usually be more profitable to expend labor in hauling out horse dung or night-soil than in building compost heaps.

Composting saves Nitrogen.

As has been said already, hardly anything is known as to the chemical changes which occur when manures or composts ferment. It is to be presumed, that, economically speaking, no process of fermentation can do much more than change the things which are originally present in the dung or in the peat into new forms. It is hardly to be supposed that enough nitrogen can be absorbed from the air and fixed in a single compost heap to be of much practical significance. And yet there are many peats, which long experience has shown to be excellent for making composts, that appear to contain only a very small amount of matters useful for vegetation. A peat of excellent reputation, analyzed by Professor Johnson, was found to contain, when in the air-dried state, three per cent of ashes, more than half of which was mere sand, and one and a half per cent of nitrogen, upon which, of course, the chief value of the material must depend. This peat was composed almost entirely of carbon, hydrogen, and oxygen, neither of which elements can be classed among fertilizing substances; whence it is plain that, excepting as regards its nitrogen, no very large amount of plant food can be got directly from a peat even so good as this one.

But there are several ways of accounting for the utility of peats that are poor in nitrogen. First of all, it is to be noticed that peat, at least when in its crude state, is an antiseptic or germicide agent of considerable power. Sour peat will kill the microdemes that cause fermentation, or prevent them from thriving, so that fermentation could hardly occur in presence of any considerable quantity of it. This fact goes far to explain how it is that peat, when used for bedding animals or for absorbing their liquid dejections, serves so well to preserve the manure, i. e. by delaying fermentation.

Moreover the humic acids in peat, even that which has been thoroughly weathered, are highly effective agents for absorbing ammonia. In this respect, Professor Johnson found that a swamp muck from the neighborhood of New Haven was capable of absorbing 1.3% of ammonia, while ordinary soil absorbed only from 0.1 to 0.5%. Heiden also noticed that a light fibrous crumbly peat used as litter in cow stables, which contained when air-dried 0.37% of ash ingredients and 93% of organic matter, of which 11% was humic acid and 0.64% was nitrogen, was capable of binding 1.6% of ammonia. He urges that such peat would be excellent for composting with night-soil, and that the product would be a good manure for light lands.

The results given in the table were obtained by Detmer in experiments where ammonia gas was passed through tubes charged with mixtures of peat and sand.

The Mixture contained		There were absorbed Grams of Ammonia.	100 Grams of Peat absorbed Grams of Ammonia.
Per Cent of Sand.	Per Cent of Peat.		
100	. .	0.093	. . .
90	10	0.187	2.06
80	20	0.311	2.37
70	30	0.654	3.80
60	40	0.996	4.70
50	50	1.090	4.18
40	60	1.152	3.72
30	70	1.245	3.48
20	80	1.339	3.30
10	90	1.494	3.30
. .	100	1.712	3.42

In Germany crumbly peat has sometimes been used even for bedding horses, in such wise that a three or four inch layer of the peat is spread in the stalls and very thinly covered with straw. It is urged, that hardly any odor of ammonia need be perceived in stables thus treated, and that it is easy enough to keep the horses clean. Conversely, it is probable that one important step in the curing of peat in dung composts is the neutralizing of the sourness of the peat through the alkalinity of the ammonia, just as in composts made with lime or with potash the acidity of the peat is neutralized by these non-volatile alkalies.

Experiments made in England in 1856 have shown, not only that peat is really effective for holding ammonia, but that peat is decidedly better for this particular purpose than charcoal made from peat. 500 grams, i. e. rather more than a pound, of peat and of peat-charcoal, respectively, were mixed with 355 grams of urine, and left to stand four days in the air together with a similar amount of mere urine. At the end of this time there was found in the plain urine as much nitrogen as would amount to 0.947 grm. of ammonia, in that which had been mixed with the charcoal 0.233 grm., and in that admixed with the peat 1.105 grm., the excess of ammonia in the last-named case being credited to the nitrogen proper to the peat.

In another experiment, where 300 grams of the peat or the charcoal, each admixed with half an ounce of urine, were left five days over sulphuric acid under a bell glass, it was found that no ammonia had escaped from the peat, while the sulphuric acid under the charcoal had absorbed 0.288 grm. of ammonia that had come to it, of course in the form of gas.

Moreover, the carbonaceous matters in peat, even in those peats that are poor in nitrogen, probably serve a good purpose for feeding the nitric ferment whenever it appears upon the scene. It has been noticed, in fact, that the nitric ferment does not flourish excepting in presence of an abundant supply of carbonaceous food. From what has been said already under Farmyard Manure, it is plain that, in order that peat or other litter shall act to preserve manure, the mixture must be kept moist and firmly compacted. The risks which attend the free admission of air to such materials will be considered more fully hereafter.

It is known from analyses made by Professor Johnson, that peat can absorb and retain nitrogen from manures in some other form than that of ammonia. Thus, a peat, which in the crude air-dried state contained only as much nitrogen as would amount to 0.58% of ammonia, was found to contain nitrogen equivalent to 1.15% of ammonia after it had lain under the flooring of a horse stable for some time, where it had been partially saturated with urine. Some of the same kind of peat, after having been composted with fish, was found to contain nitrogen corresponding to nearly 1.31% of ammonia. It would appear in these cases, not only that some ammonia had been absorbed, but that either amids or other organic compounds of some kind had been formed by the decay of the nitrogenous constituents of the dung, the urine, or the fish. The amounts of nitrogen just mentioned seem large, in view of the fact that stable manure usually contains less than 1% of this element. And if it be true, as would seem clearly to be the case, that peat has the power to absorb and hold even as much as one half of 1% of its weight of nitrogen when composted with manure, the fact is one of great importance.

Perhaps the best way of illustrating the significance of the nitrogen in peat composts will be to recur yet again to the well-known practical fact, that the application of a very small quantity of active nitrogen is often sufficient to insure the growth of large crops. A dressing of 250 to 400 lb. of Peruvian guano to the acre gives only from 50 to 70 lb. of ammonia, even if the guano be of excellent quality (15% N); and in order to obtain as much active nitrogen as this there would need to be applied to the land some 5,600 lb. of composted peat that contained 1.25% of ammonia. But in actual farm practice an ordinary rate of applying such compost is ten cords to the acre, and it is fair to suppose that each of these cords may weigh 4,000 lb. at the least.

Curing of Peat.

Thus far the argument has been based almost wholly on the preservation of manure, and very little has been said of the improvement of peat, or of any other substance used for composts, at least not directly. But enough has been said indirectly to make it evident that much more remains to be urged on this side of the question. In fact, there cannot be any doubt that peat and loam, and leaves and straw, and many other organic matters which are comparatively inert in their natural or crude state, become more or less powerful manures after they have been fermented.

Mention has already been made of the fact, that a good part of the constituents of straw remain bound up, and unavailable as plant-food, until the organization of the straw is destroyed; and the same remark will apply of course to all organized vegetable

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matters, such as leaves and stalks, and twigs or chips of wood. But by causing these inert matters to ferment, by mixing them with dung, or blood, or fish, or flesh, or any other putrescible or easily fermentable matter, their organization is quickly destroyed, and whatever of nutriment may be in them is made immediately available for crops. Thus in the fermentation of bone-meal, while the conversion of the ossein is the chief desideratum, it may still fairly be inferred that the phosphate will be laid bare, and made more readily accessible to solvents and to the roots of plants than could have been the case if the particles of bone had not been decomposed and disintegrated.

Analogy, drawn from practical experience with fermented bone-meal and fish scrap, points to the conclusion that peat and straw, or other litter, may often be greatly improved when subjected to appropriate fermentation; and Pagel has shown by methodical experiments that fermentation is really an efficient means for improving the inert nitrogen in many organic matters. He finds that much of the insoluble organic nitrogen is thus converted to soluble forms. But the fermentation must not be too violent, lest much of the nitrogen be wholly lost.

In these experiments, one set of boxes were charged with 100 lb. or more either of bone-meal or of fish guano that had been intimately mixed with some 35 or 40 quarts of either ox urine or dung liquor, and the materials were then left to ferment; while to another set of boxes, similarly charged, 10% of gypsum was added, and incorporated with the materials. The results of these trials are given in the table.

Materials used	Per Cent of original Nitrogen that became Soluble.	Per Cent of original Nitrogen that went to Waste.
1. Fish guano, urine, and gypsum (moist) . .	40.4	. . .
2. Same as No. 1, without gypsum (very moist) .	48.3	. . .
3. Bone-meal, dung liquor, and gypsum, very moist at first, afterwards dry	46.6	4.7
4. Bone-meal and urine (moderately moist) . .	80.0	39.2
5. Fish guano and small amount of dung liquor, incompletely moistened	42.5	4.3

From No. 3 it appears, as has often been shown by other experiments, that gypsum hinders the waste of nitrogen during fermentation. In No. 5 but little dung liquor was added in the beginning, in order that the fermentation might be weak and slow. Pagel urges that, in order that a fermentation may be regarded as proper, much heat must be developed by the materials. A thermometer thrust into the fermenting mixture should mark more than 100° F. The completion of the fermentation is indicated by the diminution of the high temperature. A considerable fall of temperature shows that action has ceased. But a new fermentation may be excited by forking over the heaps of materials, and moistening the dry places, best with dung liquor or urine. Too large a proportion of the urine, or other fermenting material, should not be used at first, lest violent action should occur. For the particular case of bone-meal, 25 or 30 quarts of dung liquor to 110 lb. of the meal is considered to be a good proportion.

More or less time is required for the completion of such fermentations, according as heat is developed slowly or speedily at first, and according as the heaps of material are large or small. In general, 3 or 4 weeks will be sufficient for the completion of the process, when materials such as bone-meal or fish scrap are fermented.

Straw Compost.

On farms in Sweden belonging to the crown, where legal restrictions prevent the sale of straw, the excess of this material has sometimes been composted by drenching 6 or 8 feet high heaps of it with water, in which powdered rape cake has been soaked and stirred. The moist heap, loosely covered with earth 4 or 5 inches deep, is left to ferment for a month, and is then forked over and again drenched with the rape-cake liquor. The heap is then left to itself until hauled out as manure. From 30 wagon loads of straw and 3 cwt. of rape cake, Bergstrand obtained nearly 30 wagon loads of "manure" in the course of two months and a half. On comparing the product with stable manure by means of analysis, he obtained the following figures:—

	Straw Compost. Per Cent.	Ordinary Farm Manure. Per Cent.
Water	74.36	79.30
Organic matter	15.63	14.01
Ashes	10.01	6.69
Nitrogen	0.23	0.41
Phosphoric acid	0.10	0.20
Potash	0.17	0.50

Peat Composts.

In the preparation of peat composts, dung and fish are the ferments commonly used; but urine, or guano, or the dung of fowls, would serve the purpose excellently. Blood is objectionable, because of the horribly offensive odor which is exhaled by composts prepared with it. It might not be easy to say just what the substances are which smell so offensively, but there is every reason to believe that they have no agricultural significance. There is no greater fallacy than that which gauges the worth of a manure by the stench the manure emits.

By the process of fermenting, time is gained; the organization of the vegetable matters is broken down in a few weeks or months in the compost heap, instead of resisting decay for a long time, as would be the case if the matters were left to themselves. This point might be illustrated by reference to an oak stump. Left to itself, the stump long resists decay, though the mould which finally results from its decay is rich in plant-food. But the decay could soon be effected by reducing the fresh stump to the condition of saw-dust, and fermenting this saw-dust in any appropriate way. Another striking illustration was offered by the former use of woollen rags in French agriculture. These rags, as has been shown already, contained 12 to 14%, sometimes even 16 or 18%, of nitrogen; but they decomposed so slowly in the soil that their action was felt on good moist land for 7 or 8 years, in case they were applied in the unfermented state. But when fermented by means of urine or guano-water, as was the French practice, they became a quick-acting and powerful manure.

Peat also, like the organized substances just mentioned, is often, not to say usually, very much improved by fermentation. As has been said, some kinds of peat serve very well as manure when applied to the soil directly, without weathering, fermentation, or preparation of any kind. Some sorts, moreover, ferment of themselves when thrown up into heaps, and exposed to warm, moist weather. But there are other kinds which are wellnigh useless as manures, unless they have either been rotted or fermented.

In view of these differences, it is not strange that some farmers should deem mere exposure of peat to the air to be a sufficient preparation of this material, for the practice may be judicious as regards some kinds of peat. It is often justified withal by considerations of labor and the cost of distribution. But the surest and safest way of obtaining good results with peat is to ferment it artificially in the compost heap. With peat, as with the vegetable matters, the usual fermenting agent is the dung of animals. Horse dung is esteemed to be the best kind, though urine would be better; and fish has been used largely for the purpose, especially on the southern coast of New England. Guano has been used also as the ferment, in the proportion of one part of guano to 5 or 6 parts of peat. So also have blood and the offal of slaughter-houses, fish scrap, cotton-seed meal, soap-boiler's scraps, currier's scraps, night-soil, and other easily decomposable animal or vegetable matters.

In case flesh is used, as when an animal has died from disease, it will be well to divide the flesh, and to distribute it in such manner that a tolerably equable mixture of it and the peat may be had. A small piece of flesh will ferment many times its own bulk of peat, provided it be brought into tolerably intimate contact with the peat. On account of the peculiarly offensive odor of such compost, it is best not to open the heaps except in winter weather. Such compost had better be hauled to the fields in cold weather, and ploughed under as soon as may be practicable in all cases. A similar remark will apply to composts made with night-soil. If care be taken to work upon such heaps in winter, the laborers will be less perturbed. There is one trouble with flesh-made composts, in that all the dogs in the countryside are apt to dig at the heaps.

In any event, care must be taken not to compost the flesh of animals which have died of infectious diseases. The researches of Pasteur have shown that the germs of the microscopic organism which causes splenic fever (malignant pustule), as well as various germs which produce putrefaction and septicæmia, are not destroyed in the compost heap, — not even when they are in actual contact with flesh in a state of putrefaction. Even when the diseased bodies of animals are buried in the ground at a depth of several feet, earth-worms constantly bring up the malignant germs and deposit them, in their dung, at the surface of the soil. When these worm-casts are scattered as dust, or washed about by rains, portions of them cling to the grass or other herbage, and so infect the animals that feed upon it. Pasteur has urged that animals should never be buried in cultivated fields, mowing-fields, or pastures. Whenever possible, the bodies should be relegated to poor, dry, sandy, or chalky soils, not suited for the existence of earth-worms.

One valuable resource for making compost is the kitchen sink. Suppose that, at a convenient distance from the house, a hole be dug, three or four feet deep, and of such shape that carts can be driven into it, and that a gutter be carried to this hole from the sink. By filling the hole from time to time with peat, sods, weeds, and sweepings from the house, the dooryard, and the barn, and letting the soapsuds and other refuse from the house run down upon it, a very efficient factory of manure may be created. It will be well to shade and conceal the place with a hedge of evergreens, and to have a heap of earth handy to throw in to stop smells. This method of procedure is said to have been described and commended by several of the old Roman writers on agriculture.

A still more simple method of making compost was described by Jared Eliot, in 1747. He had a long, narrow cowyard at the roadside, into which the animals were driven every night. Once a month he took down the end fences of this yard and ran a plough through it, taking care to turn furrows up to the very edges of the yard, or as near to the side fences as was possible. The end fences were then reset, and the cows kept in the ploughed yard at night, as before, during another month, and so on through the entire summer, ploughing once a month. He finally carted the ploughed earth upon the adjacent fields, remarking that, as it was very heavy, a long land carriage was not easy. He found, as he says, "that the whole furrow depth of earth was become dung, making an increase beyond what one would imagine." "I had fourfold more," he says, "than I should have produced in the common way." The dung was spread both upon grass and corn land. "I did not find but that its effects were equal to those of dung."

Alkali Composts.

Beside the easily putrescible organic matters, there are other agents capable of producing fermentation in heaps of peat or of similar materials. As practical men well know, the caustic alkalies, potash, soda, lime, and ammonia possess this power in high degree, and so do the alkaline carbonates, such as saleratus and soda ash. It was a capital observation of Angus Smith, that putrefactive fermentation will shortly set in when a soil rich in organic matter is mixed with enough alkali to saturate it, and is then left moist in a warm place. Conversely, it is known that acids and acid salts hinder putrefaction. Pettenkofer noticed that the ammoniacal fermentation of dung and urine may be checked if means are taken to prevent the materials from becoming alkaline. All is, the presence of the alkali favors the growth of the microscopic ferments, and that of an acid hinders it. Pagel, in his turn, found that moor earth which had been moistened with potash lye actively absorbs oxygen gas from the air, and that the absorption is more rapid in proportion as the surface of peat exposed is larger, as when, for example, inert matters are mixed with the peat.

Manifestly, these observations go far to explain the mode of action of alkalies in compost heaps. Lime in particular has long been an approved ingredient of composts. They serve to explain also the use by practical men of wood ashes, of peat ashes, gas lime, and mixtures of lime and salt.

Indeed, the observation of Smith goes to show that not only putrescible organic matter, but the gaseous ammonia evolved from it, is capable of exciting putrescence in the peat or loam to which it gains access. It is probable that, while American potashes are to be bought so cheaply as has recently been the case, a valuable manure for application to leachy hungry soils might readily be prepared by drenching heaps of peat, layer by layer, with weak lye in the spring, and leaving the mixture to ferment during as many of the summer months as practice might indicate.

One method, formerly common, of preparing compost, was to dig sods from beside a wall, or to plough up an old headland, or to clear out a ditch, and to throw the material thus obtained into a heap, layer by layer, with lime, or wood ashes, or manure, and to leave the heap for several months to ferment. After having been forked over to make it fine and mellow, such compost was esteemed to be an excellent top-dressing for mowing-fields.

Some of the empirical rules for the use of alkalies with peat are as follows.[1]

For every cord, or say 100 bushels, of peat, take of wood ashes 12 bushels; of leached ashes 20 bushels; of peat ashes, 20 or 30 bushels; of gas lime or spent soap-boiler's lime, 20 bushels; and of quicklime, 10 bushels, to be slaked with water just before use, or, better, to be slaked with a solution of common salt in water, or, better still in all probability, with a solution of muriate of potash instead of the sodium salt.

The peat and other ingredients are mixed as thoroughly as may be, by spreading them in layers, and the whole is built up into a compact heap three or four feet high. In case the peat is not already moist, the finished heap should be drenched with water, and then be covered with a few inches of loose peat, and left to itself. After two or three months, it is held to be good practice to shovel the heap over so as thoroughly to mix the ingredients, after which it may be covered with a loose layer of fresh peat, and left to itself until the whole of the original peat is thoroughly decomposed. Five or six months of summer weather are sufficient for the whole operation. Instead of shovelling, the heap may be ploughed over, or turned with a road scraper.

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[1] S. W. Johnson's "Peat and its Uses," p. 72.

Compost with Lime and Salt.

The use of a mixture of salt and lime, instead of mere lime, for composting peat has often been highly commended. The idea is a very old one. Sir Humphry Davy, in his work on Agricultural Chemistry, mentions the fact that several practical men have derived more benefit from the use of lime moistened with sea-water than from common lime. The late Dr. Dana, of Lowell, brought forward much evidence in favor of the mixture in his "Muck Manual"; and it has been used in the Cotton States with so much advantage, that there was talk at one time of removing a duty on salt as a means of encouraging the growth of cotton. The merit of the salt and lime mixture depends upon the facts that some caustic soda (and subsequently carbonate of soda) is formed through the mutual decomposition of the salt and the lime, and that the powerful soluble sodic alkali induces the decomposition of the peat more rapidly than could be done by the weaker and less soluble alkali, lime.

The ordinary method of proceeding is to slake quicklime with brine, and to spread the powdery product, layer by layer, upon moist peat, that has just been thrown out from the bog. Under these conditions, small quantities of caustic soda and chloride of calcium are formed from the decomposition of the salt by the lime; they dissolve in water, and diffuse into the water with which the peat is charged. But they diffuse at unequal rates, and so tend to become separated one from the other. The caustic soda diffuses faster than the chloride of calcium, and is thus enabled to act to better advantage upon the peat:

$$CaO + 2\,NaCl = CaCl_2 + 2\,NaHO.$$

The fact of the formation of crusts of carbonate of soda upon the surface of the soil in many desert places where salt and lime are in contact with one another, has been frequently observed since a very early period; and it was argued long ago, that the capillary power of the soil played an important part in the reaction. But it was not until the publication of Graham's researches on the unequal diffusion of liquids, that the manner of the formation of the crusts could be explained in a thoroughly satisfactory way. Were it not for the capillary attraction which invites the diffusion of the soda, the reaction above formulated would not occur. If lime and salt were to be mixed in a bucket of water, no evidence could be got of any such reaction as the foregoing. It is only in porous peat or porous earth that effective manifestations of it are to be seen.

There can be no doubt that the use of the salt and lime mixture is preferable to the use of lime alone, as a general rule. But now that a clew to the mode of action of the mixture has been discovered, there is room for very grave doubts whether the use of the salt and lime should be continued. The method of procedure, it will be observed, is empirical to the last degree. The success of the operation must depend in great measure upon the degree of porosity of the heap, and the best conditions for success in that particular would be hard to discover and control. Considered as a method of preparing caustic soda, or carbonate of soda, the process is simply despicable. Indeed it can hardly be doubted that soda could be applied to peat more methodically and economically in the form of black ash, soda ash, or, better yet, in that of barilla from Teneriffe.

Potash better than Soda.

But while potashes are so cheap as they are now, and are likely to continue, there can hardly be any question of using soda in any form for preparing composts. Potash is a manure in itself, a necessary form of plant food. Soda has no such claim upon the farmer's attention. Plants can succeed perfectly well without soda, and as an alkali it has no advantage over potash. The chief lesson, then, to be drawn from the "salt and lime mixture" is, that the time-honored method of composting peat with wood ashes is a good method, and that it should be inculcated and improved upon, to the exclusion of the lime and salt.

Carbonate of Lime Composts.

The use of carbonate of lime as an ingredient of composts has often been commended. At the South it is used in the form of shell marl, but in the Northern States commonly in the form of leached ashes. Some kinds of peat ashes which are used for composting in Europe contain it, and so, of course, do fresh wood ashes as a secondary ingredient, so to say. The utility of the lime carbonate is doubtless connected with the fact that it dissolves somewhat in carbonic-acid water, and that the solution thus formed is alkaline. "Bicarbonate of lime" is known to be alkaline, and it is not impossible that the faintly alkaline liquid may have some slight chemical influence in disintegrating organic matter. But the real significance of carbonate of lime in composts is, that, beside neutralizing the natural sourness of peat, it favors to a remarkable degree the growth of the nitric ferment, and so promotes nitrification.

In the light of this knowledge, it does not appear that the use of carbonate of lime by itself, as the sole agent in a compost, is specially praiseworthy, unless indeed the material to be operated upon happens to be a well-weathered peat of good quality, which is already so far cured as to be nearly or quite ready for nitrification. In this particular case, the admixture of carbonate of lime would accelerate nitrification, and might, perhaps, be the very best addition that could be made, especially if the climate of the locality happens to be warm. But upon crude peat carbonate of lime can hardly be expected to serve so good a purpose as such active chemical agents as quicklime, wood ashes, or potashes, although it may be invaluable as an adjunct to dung composts and to those made with fish, flesh, or oil-cake. And it is an open question whether, in such cases, it might not just as well be added to the heap after the first hot fermentation due to the action of the dung has passed by.

There is one case, it is true, where carbonate of lime may best be used by itself upon crude peat, and that is when the peat, as sometimes happens, contains sulphate of iron. In that event the lime carbonate will be the cheapest and best agent for decomposing the ferrous salt. So, too, when the object is merely to correct the sour, antiseptic quality of crude peat, carbonate of lime will serve an excellent purpose, although it may not act so quickly or so effectively as slaked lime. In time, however, either of these agents would neutralize both free humic acids, sulphuric acid if it were present, and ferrous sulphate.

In any event, it is important not to underrate the significance of carbonate of lime for compost making. Schulze noticed long ago that moist peat which had been mixed with powdered chalk gave off much more carbonic acid than similar peat to which no lime had been added, showing, of course, that decomposition was rapid; and Knop expressly states that, when moist, the humates of lime and of baryta, as well as those of potash, soda, and ammonia, oxidize much more rapidly in the air than humus does by itself.

Petersen has determined by methodical experiments the amounts of carbonic acid that were given off from sour humus, and from that which had been neutralized by the addition of marl, when a current of air, free from carbonic acid, was made to flow slowly over the materials. His results are as follows: —

1. One litre of a heavy, sterile clayey soil of slightly acid reaction, which contained 2% of humus, gave off by itself in the course of 16 days, at a temperature of 55° F., no more than 0.92 grm. of carbonic acid, while a litre of the same earth that had been mixed with ½% of carbonate of lime in the form of marl gave off 2.62 grm. of carbonic acid.

2. A litre of leaf-mould containing 58% of humus that had a strongly acid reaction gave off in 16 days' time, at 54° F., 0.89 grm. of carbonic acid both by itself and after 0.5% of the carbonate of lime had been added to it; but in this case the quantity of marl used was insufficient to neutralize the acidity of the leaf-mould. In another trial, however, where the acidity of the leaf-mould was neutralized by mixing with it 3% of the lime carbonate, 5.35 grm. of carbonic acid were given off in 16 days' time.

All these results are readily explicable by what is now known of nitrification. Neutralization of the sour humus promoted the activity of the nitric ferment, and the quantities of carbonic acid evolved in the several instances were probably pretty accurate measures of the amounts of nitrification which occurred in the different samples of earth. As has been already insisted, a trace of alkalinity in the soil, and air, moisture, warmth, carbonaceous food, and ammonium compounds, constitute favorable conditions for nitrification. It is possible, moreover, that in some of these instances other kinds of fermentation, such as those which produce ammonia, may have occurred. It is not unlikely, indeed, that they may sometimes have preceded the nitric fermentation. Experiments on the fixation of free nitrogen from the air, such as were described in the chapter on Vegetable Mould, go to show that fermentations which occur in the presence of alkalies may often be preferable to other modes of decay. Still it is not to be expected that a compound so feeble in the chemical sense as carbonate of lime can act upon crude peat and other rough materials with the vigor of a true caustic alkali; though the carbonate is a useful agent, nevertheless, and may perhaps always do some good when present in a compost heap.

Old mortar or plastering and soap-boiler's lime cannot be classed too strictly as carbonate of lime, since they are apt to contain a small proportion of caustic lime. Either of them would serve a useful purpose for neutralizing the humic acids in crude peat, and would subsequently help nitrification. Even spent gas lime, in spite of its containing poisonous sulphides and sulphocyanides, may perhaps be well fitted for correcting the sourness of crude peat, as a preliminary to composting the peat with dung. For this purpose, however, it should not be used in excess.

The following experiments were made by Professor Johnson at New Haven, to test the effect of alkalies in developing the fertilizing power of peat. Pairs of pots were filled, —

1. With peat alone (270 grm. in each pot).
2. Peat and 10 grm. ashes of young grass.
3. Peat and ashes (as before), and 10 grm. carbonate of lime.
4. Peat and ashes, and 10 grm. slaked lime.
5. Peat, ashes, and lime, and salt for slaking.
6. Peat and ashes, and 3 grm. Peruvian guano.

Five kernels of pop-corn were planted in each pot, and the pots were watered with pure water, and the plants were allowed to grow until those best developed ceased to feed upon the soil but upon their own lower portions, as shown by the withering of the lower leaves.

The air-dried crops were as follows : —

	Weight of Crop in Grams.	Comparative Weight of Crop.	Ratio of Weight of Crop to Weight of Seed.
1. Peat alone	4.20	1	2½
2. Peat and ashes	32.44	8	20½
3. Peat, ashes, and carbonate of lime	38.44	9	25½
4. Peat, ashes, and slaked lime . .	43.22	10	28½
5. Peat, ashes, lime, and salt . . .	46.42	11	30½
6. Peat, ashes, and guano . . .	53.78	13	35½

The object of the guano was to have a standard of normal action.

The peat alone was in this particular instance incompetent to supply all the food which was required; the peat and ashes did better, while by the action of the alkaline materials the inert nitrogen of the peat was made really active, and the crops grew tolerably well. The differences between the three alkalies are well marked, though of course the ashes alone were somewhat alkaline. Mention has already been made of Boussingault's observation, that the addition of caustic lime to loam largely increases the amount of ammonia contained in it, through decomposition of inert nitrogen compounds in the humus.

Action of Lime on Dung.

In connection with the subject of the action of alkalies on peat, some mention should be made of their action upon fresh dung, or on dung that is fermenting in moist heaps, although not much is known accurately concerning these matters.

From dung which is undergoing hot fermentation, caustic lime or any other of the fixed alkalies will of course expel large quantities of ammonia; but there is some evidence which goes to show that lime does good rather than harm when spread upon the surface of ordinary moist dung-heaps, and Payen has urged that the addition of small quantities of lime to fresh dung or urine retards their decomposition considerably instead of hastening it. There seems to be an actual union between the lime and some of the nitrogenized substances when they are in the fresh condition, as will be explained in another place.

The following experiment, by Wolff, is of interest. He mixed 250 grams of quicklime, that had been allowed to slake in the air, with fresh cow manure in a box of one cubic foot capacity, and left the mixture to decay in a north room during 15 months. It weighed some 11,000 grams at first. The loss of weight from this mixture was rather more rapid, and was larger in amount, than occurred with similar boxes of mere manure, and of manure and gypsum, which were tested at the same time. But it appeared that, as was the case with the gypsum also, the final product contained a smaller proportion of soluble organic matters than dung which had rotted by itself; whence the conclusion that the lime must have combined with certain organic matters to make them insoluble. It is probable, withal, that some of the matters thus fixed by the lime would have decomposed very readily if left to themselves. The limed manure contained, when rotted, more organic matter, and more nitrogen also, than the simple rotted manure; and there was a larger proportion of nitrogen in the organic matters of the limed manure, both in those that were soluble and those which were insoluble in water.

Composting Refuse.

Almost everything that has been said of composting peat, either with dung or with an alkali, will apply to a multitude of other materials beside peat. As regards straw and leaves, indeed, and other easily decomposable vegetable substances, the theory and practice of fermentation seem to be tolerably well understood. But there are many things, such as the stalks of corn, of potatoes, of buckwheat, and of beans, twigs clipped from hedges, bushes mown in pastures, chips and sawdust, clods and weeds, which can be perfectly well decomposed in the compost heap by proper treatment, and which could probably be economically decomposed there, instead of being burned to ashes as is now done far too frequently.

It is well no doubt to burn trash for the mere sake of getting rid of it, and the use of fire often seems to be justified also as a means of destroying fungi, the eggs of insects, and the seeds of weeds; but in all probability the destruction of these pests could be readily effected by means of weak solutions of potashes, and the nitrogen of the organic matters that harbored them be saved at the same time for the farm. Rubbish thus drenched with potashes would naturally decay quickly in warm weather, if it were kept in a damp place.

Even slaked lime, admixed with weeds in the proportion of 10 or 15% of quicklime to 85 or 90% of weeds, is said to decompose them so speedily that the mixture is fit for use next spring, though the lime would not be nearly so apt as potashes to destroy all the seeds. In general, soluble alkalies, like potash and soda, or their carbonates, must act much more effectively to destroy weed seeds than any method of merely composting with dung, although it is true enough that some seeds are destroyed in heaps of dung compost.

It has been recommended in Europe, in cases where the fodder or the litter contains many weeds, to compost the manure with loam, and to drench the heaps frequently with dung liquor in order to rot the weed seeds. The practice is akin to a plan for killing cotton-seeds formerly in use at the South, though far less effective because of the superior resisting power of the weed seeds. It has been noticed recently that the seeds of various weeds do not perish in silos of corn-fodder, even when much heat has been developed by the fermentation. It would appear that only those seeds are destroyed in a silo which are soft enough to swell under the conditions which obtain there. The mere heat of the place is not high enough to destroy many of them.

The chief points to be considered in composting coarse materials are, that more time must be allowed for their decomposition than for the decomposition of finely divided substances, and that special care must be taken to make the heaps of coarse materials large, and to keep them moist. It is evident that, in order to the best results, the coarse materials should be fermented by themselves in special heaps. There would be a waste of time, and risk of losing fertilizing matters, if fine materials were left to rot with coarse during the long time necessary for the decomposition of the latter.

A general idea of the value of some common kinds of refuse may be got from the following table, which gives in round numbers the percentage proportion of water, nitrogen, and ash ordinarily contained in them.

	Water.	Nitrogen.	Ash.
Wheat straw, fresh	19	0.3	....
Wheat straw, dry	5 to 12	0.5	4 or 5
Wheat stubble, dry	5	0.4	....
Wheat chaff, "	8	0.9	8 or 9
Rye straw, "	12	0.2 to 0.4	4 or 5
Barley straw, "	12	0.2 to 0.3	4 or 5
Oat straw, fresh	21	0.3	....
Oat straw, dry	13	0.3 to 0.4	4 or 5
Pea straw, dry	9	2.0	5
Buckwheat straw, dry	12	0.5	3 to 5
Potato vines (tops and leaves) withered	76	0.6	2 to 5
Potato stalks, dry	13	0.4	2 to 5
Beet leaves, withered	89	0.5	2 or 3
Carrot leaves, "	71	0.9	2 or 3
Leaves of hard-wood trees as raked up in autumn	40 or 50	0.8 to 1.2	....
Ditto, dry	15	....	4 to 6
Pear leaves, dry	15	1.4	....
Spruce sawdust	24	0.2 to 0.3	....
Oak "	26	0.5	....
Apple pomace	77	0.2	0.5
Grape husks	48	1.7	....
Refuse hops	73	0.6	....
Sod	...	0.5	....

Looking at the matter from the two points of view which have been insisted upon, — viz. 1st, the preservation of dung, and, 2d, the decomposition of inert vegetable matter, — it would seem as if in general, at least for all farms where stock is kept, that only the coarser sticks and stalks and clods should be treated with a special view to their fermentation, and that the finer straw and leaves, as well as peat and loam and clay, should serve in the first place as bedding for cattle, or as absorbents of their liquid dejections. The finely divided materials will usually be sufficiently decomposed when thus treated, without need of special oversight. But if all the coarse materials were banished to special heaps, there would seem to be less need of that incessant forking over of dung and compost heaps upon which so much labor was formerly expended, and still is, indeed, on many farms. The cost of merely moving manure from the stable to the field, which commonly involves the carting of it twice and the handling of it four or five times, would seem to be sufficiently expensive, under the most favorable circumstances, without expending any more labor than can possibly be avoided in repetitions of the turning process. It must be admitted, however, that very little is known as to the reasons why the practice of forking over manure persists. Perhaps there are other points gained by the process beside the mere decomposition of the long litter. Although there is some diversity of opinion with regard to the advantage of turning over compost heaps, the general impression among farmers seems to be, that the oftener the heaps are worked over during or after fermentation the better.

It is noteworthy that, in regions where the winters are mild, compost heaps are sometimes covered over at the beginning of winter with straw, sods, brush, potato tops, or the like, and occasionally even with horse manure, in order to exclude frost. In this way the heap is kept unfrozen, so that its contents can be removed to the fields at any time. Perhaps such protection might be usefully applied with us both to compost heaps and heaps of peat that are to be used in midwinter for compost-making. It deserves to be studied whether the old plan of planting squashes, pumpkins, melons, or other free-growing plants, upon compost heaps, has any other merit than that of yielding a small crop at trifling cost, and of hiding the heaps from view. The shade and surface moisture afforded by the plants may perhaps promote nitrification; but, on the other hand, the plants must necessarily pump up great quantities of water, and tend to dry out the interior of the heap.

A good deal of importance is attached by some writers to the idea that compost should be "ripe" when applied to the land; and it is taught that the time needed to ripen a compost heap may vary all the way from a few months to two years, according to the materials and to the season. Care must consequently be taken to establish the heaps early enough, that they may be ready for use at times when fields are to be planted. Perhaps the best plan of all is to have a number of heaps in all stages of progress toward ripeness.

The chief advantage gained by stirring compost seems to be, that, up to a certain point, fermentation sets in anew each time the heap is turned over, and its contents are loosened and exposed to the air.

It may be true, also, that the formation of nitrates or nitrites is promoted by the admission of air to the mass, though this point is problematical as regards the interior of the heap. So far as the establishment of a new fermentation goes, the occasional turning over, at leisure moments, of those compost heaps which contain coarse material would seem to be judicious; but the process would seem to be open to adverse criticism as regards ordinary heaps, such, for example, as those composed of peat and dung. If the object in forking over the heap is merely to decompose the peat somewhat more thoroughly, it will be well to count the cost of the labor involved before much of that kind of force is expended for what is probably a comparatively small gain. Even if it be admitted, for the sake of the argument, that the compost is decidedly benefited by being worked over, it may still be urged that the benefit is not commensurate with the cost. It would probably be far more judicious, in most cases, to expend the labor either in hauling or in getting out new supplies of peat or of sods, and in establishing new heaps of compost, rather than in turning over the old heaps; provided always that the materials of the heap are in a tolerably finely divided condition.

For horticultural purposes, indeed, it may often be well to turn over a heap of dung or of compost many times and often, in order to provide delicate food for some cherished plant. But in agriculture the methods are coarser. An abundant supply of tolerably crude manure will usually serve the farmer a better purpose than a scanty supply of manure that has been highly refined; and he can nowadays always buy a little nitrate of soda or of an ammonium salt to enliven the manure, if need be.

One great advantage in composts is, that they can be made far from home. Suppose, for example, that there is an outlying field that needs to be fertilized. It will often be better practice to get out pond mud, or peat, or sods, at the locality itself, and haul thither enough dung, or lime, or ashes, to compost the inert materials, than it would be to haul dung enough to manure the entire field. A similar remark will apply to home fields, which are not readily accessible at certain seasons.

One word should be said about the forking up of great heaps of manure in the spring by the market gardeners, where the chief motive seems to be the using of the heat of fermentation. When brought to the cold ground, the hot manure warms it considerably, as will be explained in a subsequent chapter, and so insures a better start to the early peas or other vegetables that are to be grown there. Horse manure is esteemed for this purpose, and that which contains straw is held to be better than that which is mixed with bog-meadow hay. In this case the gardeners are really seeking to get a feeble form of bottom heat, such as is seen at its best in their hot-beds. Twenty-five cords of such manure to the acre, which is a not unusual application, are clearly competent to force an early crop, both by virtue of the heat developed, and of the large amount of nitrogen which the manure contains. It is probable, withal, that nitrification speedily sets in where the land has thus been prepared and warmed, as if for this special purpose, by working into it such large quantities of manure.

CHAPTER II.

DRY LOAM MAY INJURE MANURE.

THUS far it has been argued that the mixing of peat, loam, or straw with dung is in the main advantageous as a means of preserving the manure, provided the mixture is kept moist and cool, even if it be exposed to the air. But there is another side to this question of admixture, for it is known that when dung or urine is mixed with an excess of dry loam or dry peat, and then exposed to the free action of the air in loose heaps, there is danger that a good part of their nitrogen will be lost. Indeed, observations are not wanting to show that the admixture even of moist loam with decaying organic matters does not always hinder the loss of nitrogen.

It has been shown by Lawes and Gilbert, by Schloesing, and by Armsby, that when nitrogenous organic substances undergo decomposition in presence of much oxygen, large quantities of free nitrogen gas may be evolved from the materials. Inasmuch as this loss of nitrogen appears to depend upon some process of oxidation, the importance of hindering free oxygen from gaining access to the interior of manure heaps is apparent.

The Oxidation is caused by Ferments.

According to Pasteur's teachings, the decompositions now in question must depend upon the presence of aerobic ferments, which serve to carry oxygen from the air to the constituents of the organic matter, and to "fix" it upon them. But dry earth, or any other porous substance which can promote the division of the organic material, and increase the number of points of contact between it and the air, must favor the multiplication and the effective working of the ferment.

As has been said already, under Dung, — beside putrefaction proper, and the anaerobic fermentations, which need no air for their completion, — there are processes of true decay, or slow combustion, which, though due like the others to the action of microscopic ferments, are characterized by the fact that air is necessary for their progress. It is the so-called aerobic ferments which cause the decay of manure in loose heaps, and the waste of humus in cultivated fields; and it commonly happens, while one kind of fermentation may be going on at the centre of a dung-heap to which no air has access, that decay of a totally different order is progressing at the surface of the heap; as deeply, that is to say, as air can find entrance to the materials.

It is to be observed, furthermore, that porous substances, such, for example, as dry earth, or charcoal, or, better yet, spongy platinum, may exert a powerful influence upon foul gases to destroy them.

These decomposing actions of porous bodies are well shown by a common lecture-room experiment, which consists in covering the body of a rat or squirrel with a little heap of bone-charcoal, and leaving the heap undisturbed for some weeks. It is then found that the putrescible portions of the animal have disappeared, and that little or nothing of him is left but bones and hair. But meanwhile no odor has been perceived to arise from the heap of charcoal, excepting a very faint smell of ammonia. So long as any moisture is left in the animal, his flesh probably decomposes rapidly by the action of aerobic ferments, and in case any of the products of the decomposition are offensive, they would be absorbed and destroyed by the porous coal.

There appear to be three points worthy of special notice in respect to this so-called disinfecting action of charcoal; viz. the easy access of air to the organic matter, through the loose particles of the coal, whereby the activity of aerobic ferments is promoted; the power of the coal to absorb gases; and the fact that the gases thus absorbed react chemically upon one another. The charcoal absorbs the offensive gases into its pores, together with air, and thus forces

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the oxygen of the air into such close communion with the gases that the latter are burnt up and destroyed. In some foreign cities, sieves of charcoal have been placed across the air-vents of sewers in such manner that the outgoing air should all be filtered through the charcoal, and so be disinfected.

It is to be noticed that, in all cases, the charcoal, far from exerting any preservative influence, actually hastens the decomposition of the organic matter. Its action was well exemplified in the case of some trout caught by a student in New Hampshire, and packed in charcoal powder there to "preserve" them, but which, on being sent express to his friends in Boston, were received by them in an advanced stage of decomposition.

As a matter of course, dry earth will act in very much the same way as charcoal, though to a less degree. The habits of mankind with regard to the burying of dead animals, and of all offensive matters, well illustrate this point. Doubtless the earth may do good service by destroying offensive gaseous emanations from the putrefying matters, as charcoal does, but it must often happen that buried materials will be simply destroyed, which, by proper treatment, might have been saved to serve as fertilizers.

Destructive Power of Porous Earth.

To repeat, the destructive power of earth is mainly a consequence of its porosity. The drier the earth, so much the greater will its destructive power be, for in moist earth most of the pores are filled, and stopped up, as it were, with water. But even moist earth must exert some of this destructive power, unless it be tightly compacted; and in most manure heaps some parts of the heap will be loose enough and dry enough to be subject to more or less of this kind of decay.

It is an admitted fact in natural philosophy, that, by force of adhesion, every solid substance exposed to the atmosphere, or to any other gas, is covered with a thin film or coating of air, or of the other gas. To some substances, like metallic platinum, gases adhere with peculiar force, and so they do to many porous bodies; i. e. substances whose interstices present a large surface in proportion to their bulk. A familiar instance of such adhesion is seen in the clinging of tobacco smoke to curtains and other woollen articles; and, as has been said, more or less carbonate of ammonia may be retained by the soil in this way, especially by clay. (See "How Crops Feed," p. 243.)

The air or other gas thus held as a film upon the solid substance must evidently be very much compressed as compared with atmospheric air, and must consequently be peculiarly ready to act or to be acted upon chemically. Moreover, air thus held attached to porous bodies may serve as a reservoir or source of supply for the support of microdemes, even in the midst of a great heap of inert materials.

Perhaps because the substances experimented upon vary so widely in respect to porosity, it is not easy to obtain clear conceptions as to the limitations of these facts, or as to their practical importance in respect to the preservation or destruction of heaps of ordinary compost or dung. For instance, there is an experiment by Wolff, in which 150 grams of finely powdered charcoal were packed with cow manure in a cubic-foot box, and left in a north room for 15 months. The mixture, which weighed about 15,000 grams at first, hardly lost weight any more rapidly than the mere manure with which it was contrasted, and it contained as much nitrogen as the latter at the close of the experiment.

"Earth-closets" destroy Manure.

It has been pretty clearly made out that the oxidizing power of dry earth, when loose or not tightly packed, is a matter of very grave significance in its bearings upon the so-called "earth-closet" system of disposing of human excrements. In this system, as is well known, the idea is to cover up the excrement instantly with dry earth. Sifted garden loam is best; clayey loam is good; but fine coal ashes will do very well, except that they are rather too dusty for comfort.

There is provided, in place of the fixtures of the ordinary water-closet, a somewhat larger set of pipes, for the transmission of powdery earth instead of water, and these pipes are connected with a reservoir of dry earth above. Upon opening a valve, the dry earth flows down as if it were water, and passes into another reservoir below, whence it can be removed from time to time, as occasion may require.

When human excrements are thus covered with fine dry earth, their odor at once ceases to be perceptible, and no further annoyance can arise from them. All fermentation, in the ordinary meaning of the term, is prevented, and the excrement is deodorized so completely, that one and the same barrel of earth may be used over and over again, and finally carted away without offence, precisely as if it were mere loam or ashes, since, except for a suspicion of ammonia, it has no odor other than that of earth. Except for the trouble of keeping up the supply of dry earth, it would be difficult to say too much in favor of this system. As a sanitary device, it has very great merit, and is doubtless the next best system to that of water-closets which has yet been devised.

It was thought at one time that the general adoption of earth-closets in villages and small towns would be a distinct gain for agriculture; for, even if it were admitted that the system is imperfect as a means of preserving manure, it was believed that it must still be vastly better than the methods in common use. Hence it was supposed that an enormous amount of fertilizing material that now goes to waste would probably be saved.

But it is plain from what has been said already of the powers of dry earth, that the earth-closet must be a very imperfect device for saving manure, both because so large an amount of earth has to be used in order thoroughly to absorb the liquid portion of the manure, and because of the tendency of microdemes in the earth to burn up and destroy the dung. In point of fact, it has been found that the amount of nitrogen retained by the earth is but inconsiderable, even when the earth has been repeatedly used.

Voelcker found in loam which had been used four times in an earth-closet, and dried by fire heat each time after use, no more than 0.39% of nitrogen, 1½% of bone phosphate of lime, and 1⅓% of potash. At another time he analyzed loam of a somewhat different character that had been used five times in the closet, and dried by fire heat four times, and finally been allowed to dry in the air after the fifth use. This material contained 0.41% nitrogen, 1% bone-phosphate of lime, and 0.66% potash. No nitrates could be detected in either of these samples.

Yet again, he analyzed materials from a prison at Wakefield, and obtained the results set forth in the table. For the sake of ready comparison, all the figures are calculated for earth dried at 212°.

	Earth before Use.	Earth once used.	Earth twice used.	Earth thrice used.
Organic matter and water of constitution	9.88	9.79	11.53	12.22
Alumina and oxide of iron	12.95	16.15	14.11	12.48
Phosphoric acid	0.18	0.25	0.44	0.51
Magnesia	1.44	2.63	0.77	0.90
Alkalies and loss			0.72	0.74
Insoluble, clay and sand	71.99	68.93	70.30	71.01
Nitrogen	0.31	0.37	0.42	0.51

The original earth was a clayey garden loam, that contained when ready for use 10% of moisture. The used earths contained from 12 to 22% of moisture, according to the state of the weather.

It will be seen from the table that there is only a very small increase in the proportion of nitrogen each time the earth is used. The increase of phosphoric acid, though larger than that of the nitrogen, is still small. A ton of the thrice-used earth would hardly contain 10 lb. of phosphoric acid. The once-used earth contained only 0.06% more nitrogen and 0.07% more phosphoric acid than the original loam.

In experiments upon a somewhat different plan, made by Dr. Gilbert, 14 cwt. of air-dried clayey loam were sifted and put aside for use. When from ⅓ to ½ of this store had been used, it was necessary to empty the pit. The mass was found to be uniformly moist throughout, though neither fæcal matter nor paper could be seen in it. This once-used earth was spread upon the floor of a shed to dry, and was then resifted and again passed through the closet. Analysis of the materials gave the following results:—

	Before Use.	Once used.	Twice used.
Moisture expelled at 212° F. from the air-dried, sifted soil	8.440	9.970	7.710
Per cent of nitrogen in air-dried, sifted soil .	0.067	0.216	0.353
Per cent of nitrogen in soil dried at 212° . .	0.073	0.240	0.383

As Dr. Gilbert has observed, the twice-used soil is no better than good garden loam. It could not bear the cost of carriage, except to a very short distance. It would appear, nevertheless, from English experience, that when the closets are fed with garden loam, and the used earth is immediately applied as a fertilizer, crops may derive some benefit from it. When applied at the rate of from half a ton to a ton to the acre, it is said to have been beneficial to grass-land, potatoes, onions, and other vegetables.

In this country, Colonel Waring, at Newport, purposely kept a couple of tons of the dry earth for a number of years, and had it used over and over again, in order to see how often it could be used without losing its efficiency. The material consisted of a mixture of about 1 part loam and 3 parts coal ashes. The closets were filled about 6 times a year, and when the vaults were emptied, the earth was thrown into a heap in a well-ventilated cellar to dry. Waring states that the material which he sent to be analyzed must have been used at least ten times, and that it was the same to all outward appearance then as it had been in the beginning. It had no odor, and it looked and felt the same as at first, and it seemed to be just as efficient in the closet as ever.

From Professor Atwater's analysis of this ten-times-used material it appears that it contained 1.31% of moisture, 10.72% of organic and volatile matters, 0.37% of phosphoric acid, and 0.28% of nitrogen. Whence it appears that, excepting a slight gain in respect to phosphoric acid, the material had not been practically improved by its tenfold use. Neither the dung nor the urine with which the earth and ashes had been so often charged had made much impression upon it.

Waring urges that the amounts of these foreign matters added to the earth were by no means slight. He computes that the use to which the closets were put was equal to that of four adults for six years; and since an adult voids 23 lb. of dry matter per year in the fæces and 34 lb. of dry matter in the urine, — of which last he admits that one third went into the closets, — there would be about 34 lb. of dry manure go into the closets every year for each person, excluding paper from the account. Hence the four people in six years would yield over 800 lb. of dry solid manure, containing more than 230 lb. of nitrogen.

From the analysis, it appears that Waring's two tons of material contained only about 400 lb. of organic and volatile matters, some of which was undoubtedly "water of constitution" that would not go off at 212°, and it is to be inferred that a considerable proportion of this organic matter was already contained in the earth at the beginning. Atwater's analysis shows only 11 lb. of nitrogen in the 2 tons of Waring's used earth, which is no more than was contained in 2 tons of the fresh earth (garden loam) analyzed by Voelcker. It would appear that, practically speaking, in this case nearly all the organic matters of the excrement and the paper must have been burnt up and destroyed.

Professor Johnson assures me that he too made analyses of used earth from Waring's closets some years earlier, and that the results were similar to Atwater's. They seemed so extraordinary, that Waring could not bring himself at that time to publish them. Of course, the results as now stated are all the more striking, inasmuch as they relate to a longer term of years.

This palpable destruction of manure by dry earth is likely to cast discredit upon one at least of the instances where loam is used for bedding animals. It was formerly thought that, for sheep, bedding with loam must certainly be a commendable practice, since, in view of the comparative dryness of the excrements, there is much less risk than there is with cows of the animals being unduly soiled by contact with the earth whenever it happens to be moistened. But, as has just been stated, there is good reason to believe that this very dryness is a source of danger for the manure.

Composts of Night-soil.

In connection with the subject of the earth-closet, it needs to be said, that some of the best of the agricultural methods of treating night-soil have little or nothing in common with the use of dry earth. They are really systems of composting with peat, or loam, or sods. Either layers of peat thick enough to absorb the urine are frequently shovelled into a shallow vault, which has been constructed so as to facilitate the addition of the peat and the removal of the mixture, or a considerable excess of peat is strewn at intervals upon the contents of an ordinary vault, and, as often as occasion may require, the mixture is hauled out and thrown up into compact heaps. These heaps are bottomed with peat, and loosely covered with it also, and are then left to ferment.

This method of procedure, there is small need to remark, differs essentially from the dry-earth system. It is nothing more than a particular instance of the ordinary method of composting. The excrement serves as a basis for fermentations by virtue of which the inert matters in the peat are decomposed and converted into new compounds fit for the nourishment of plants. Meanwhile the antiseptic peat hinders for a time the dung from passing into wasteful forms of fermentation.

It is worthy of remark, that, in the country, vaults are objectionable, unless indeed they are very shallow. Not only may they readily become sources of disease, but the process of cleaning them out is always a highly disagreeable task, and sometimes actually dangerous. Doubtless a large part of the prejudice which exists against the use of night-soil is to be credited to the horrible stench which arose from the old-fashioned vaults whenever their contents were disturbed.

Methods of Dealing with Night-soil.

One way of handling the mixture of peat and night-soil above mentioned is to have the receptacle consist of a box or tub, — an old cart-body, for example, — set on a stone-boat or drag, so that it may be hauled into the field without offence, and there be capsized with handspikes. It is still true of such compost, that its odor is vile. Hence good judgment should be exercised as to the times at which to move it, and the fields upon which to put it. In any event, it is well to plough night-soil or blood composts under as soon as may be convenient.

Considerable quantities of night-soil are still hauled out from some parts of Boston, in the form of a thick muddy liquor, to be used as manure. Forty or fifty years ago, when the employment of this material was more common, or at the least more conspicuous, than it is now, the plan was sometimes adopted of allowing the liquid to run out upon the land to be cultivated, where it soaked into the soil, and was subsequently worked in by processes of ploughing and harrowing. But a more common plan was to prepare a compost bed at the edge of the field, by ploughing up a patch some twenty or thirty feet in diameter and making a rim of earth a foot or so high around it. The night-soil was allowed to flow into and fill this basin, where much of it soaked into the earthen floor and some part of the water evaporated.

Loam, or well-pulverized peat that had been exposed to the air for a year or two, was then thrown upon the surface of the mud, together with plaster of Paris in many instances, and when the matter was dry enough to handle it was forked over, sometimes twice, as a preparation for its distribution upon the fields. The farmers who made these composts preferred them to fresh night-soil, and found that they did good service. Probably large quantities of nitrates were contained in the finished products. The use of plaster in this case seems commendable.

One method of applying night-soil, in use in Europe, is to scoop out, at appropriate distances from one another in the field to be manured, a number of shallow holes or cups two or three feet in diameter, to run the liquid night-soil into these holes, and to throw it from them upon the surface of the land.

Real Danger of Night-soil.

It was thought formerly that various chemical substances prejudicial to health are liable to be produced by the decay of human excrements, and that the dangers which are known to arise from keeping excrements stored in vaults, or from allowing them to soak into the earth around dwelling-houses, must be attributed to this cause. Nowadays rather less importance is attached to this old conception, although it is still recognized that there may be something of truth in it. Perhaps it is only under quite exceptional conditions that any serious danger to health can arise from the chemical products of decaying night-soil.

The real trouble seems to be, that excrements do at times serve as the home and breeding place of certain microscopic organisms, one or another of which may cause a particular disease, — such, for example, as dysentery, typhoid fever, cholera, or diphtheria. It is only when the special microdeme which occasions one of these diseases is present in the night-soil, or in the earth or water into which night-soil has soaked, that there is any great danger in having it about. Nevertheless, it may often happen that night-soil will contain less noxious, though still hurtful organisms, such as might occasion diarrhœa, or cause inflammation to set in upon any trifling cut, or scratch, or abrasion of the skin, with which a little of the night-soil, or emanations from it, may have come in contact. All this beside the depressing effect of the offensive odor, which, for some organizations, might be sufficient to predispose the system to disease. (See subsequent chapters for Night-soil and Sewage.)

Composts regarded as Saturated Earths.

There is still another way of looking at composts beside those already described, and it is the usual method of regarding them; namely, as "earths saturated with easily assimilable plant-food." There are plenty of cases where the crop will succeed better when treated with such saturated earth than if it were dressed with clear dung. Take the case of "dunging in the hill," for example; it will manifestly be better to have a shovelful of compost left in contact with the seed than a mass of dung. For fresh dung might rot the seed, and hot manure would be likely to "burn" it, as the term is. Moreover, crops like beets and potatoes have no such powerful roots when young that they can afford to search for their food at great distances. They do best when a "saturated earth" is supplied to them in the beginning close at hand.

Again, for top-dressing mowing-fields and pastures, the saturated earth is specially well fitted. There are some soils withal, such as dry sands, where dung does not decompose advantageously, and it is precisely on such soils that the saturated earth does most efficient service. But, as hardly needs to be said, this saturated earth theory is taken somewhat after the fact. It concerns itself with the uses to which the product is to be put, rather than with the scientific explanation of the mode of manufacture.

Composts are really Earths charged with Microdemes.

In the light of existing knowledge, it is more reasonable to consider composts as earths charged with microscopic organisms, such as bring soils into a good state of fermentation and help to increase fertility either by changing into new forms matters which are already contained in the soil, or by working to fix free nitrogen from the air. In order to grasp this conception clearly, the student will do well to contrast ripe compost with crude and barren earth, such as may often be seen upon the sides of ditches, roads, and railways where banks have been cut through. Earth thus laid bare may remain sterile even for several years after the excavations are made; and the inference is, that it does not contain the organisms which promote fertility. In the absence of these organisms, no proper fermentation can occur, and the earth remains infertile. But by strewing a good compost upon such land it would not be difficult to establish vegetation upon it, especially if pains were taken that the slope should not be too steep, and if a furrow were drawn upon the land at the upper edge of the slope to lead away rain-water, and so prevent the slope from being washed and gullied.

Phosphatic Compost.

In case a compost were to be applied to a root crop, there can be little doubt that it would be well to have some phosphate incorporated with it during the process of preparation, such as bone-black, or bone-ash, or ground phosphatic guano, or one of the better kinds of ground phosphate rock (i. e. "floats," so called). Experience teaches withal, that precipitated phosphate of lime is an excellent application for root crops, and it seems plain that one good way of applying it will be in the form of compost.

It is a very interesting question anyway whether bone-ash or bone-black can be much acted upon either by the acids naturally contained in peat, or by the carbonic acid which results from the decay of organic matter. Many experiments have been made of late years to test this point, and it is a subject well worthy the attention of farmers in poor countries.

It may fairly enough be inferred that sour peat admixed with bone-black, and kept moist, will combine therewith to the neutralization of its own acidity and the improvement of the phosphate. The idea is similar to that which justifies the use of bone-ash or bone-black on the reclaimed gravelled meadows of North Germany. Guerin reported in 1858 an instance where, by the application of bone-black alone, rye was grown with great success, for seven consecutive years, on land so sour that it had been regarded as unproductive before the application of the phosphate. Peruvian guano, of equal money value with the bone-black, applied for the sake of comparison to another parcel of the land, failed to bring a crop of rye, since the plants all ran to leaf. It seems probable, in this instance, that, beside the direct chemical action of some of the constituents of the bone-black to neutralize the humic acids, fermentations may have been induced by the presence of the phosphate, whose products would serve in their turn to neutralize the acidity of the soil, as well as to promote the growth of the crop.

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CHAPTER III.

MODES OF APPLYING MANURE.

With regard to the methods of applying manure to the soil, it is extremely difficult to lay down general rules applicable for all cases. But there are still some things which may be said. It is easy, for example, to object to a system which prevails somewhat in the vicinity of Boston upon gentlemen's estates, of spreading farmyard manure upon the surface of lawns in late autumn or early winter, in such positions that some part of the goodness of the manure must be washed away by every rain that falls upon the frozen ground.

The objection here is simply from the chemist's point of view. It may be possible, perhaps, that the habit has its advantages, both as a means of maintaining a thick stand of grass and of saving labor, though the probabilities are that it has been imported from a mild European climate, and applied here thoughtlessly. It seems but reasonable to maintain that winter top-dressing should be restricted to level fields, for both rain and melted snow must sweep manure from frozen hillsides before its constituents can have had any fair chance to soak into the earth.

Spreading Fresh Manure.

The practice of carting out fresh manure from the barnyard as fast as it is made, and spreading it directly upon the fields, even in winter, has frequently been advocated abroad, and has been commended by several good farmers even in New England, though it may be doubted if they were hill men. The chief gain, no doubt, is in the saving of labor. Indeed, it can well happen that the farmer may find so much advantage in having his teams and men haul out and spread manure at an idle season, in order that they may be free for other work when it presses, that he can afford to put up with considerable losses of manure in the field, no matter whether they be caused by sweeping rains or by hurtful fermentations. It must be remembered withal, that the manure would have probably suffered some loss anyway, even if it had been left in the barnyard.

The spreading of short manure upon grass in the spring, or in the autumn even, is no doubt commendable in many situations, as a means of maintaining the field in good case; and, as has already been insisted, the surface spreading of manure in temperate climates, like that of England, may be really advantageous, even in winter, since the unfrozen ground absorbs much of the goodness of the manure.

Chemists are prone to believe that the formation of nitrates from the nitrogen compounds of the manure will be promoted by surface spreading, and that these substances may remain inert and unacted upon when buried in a soil of close texture.

One objection to the system of surface spreading, true especially of light, leachy soils, is that the non-soluble portions of the manure, as they lie upon the surface of the ground, are liable to dry out to a peat-like substance, which probably exerts very little, if any, useful effect upon the growth of crops.

Best Depth to bury Manure.

It seems plain that, as a general rule, manure should be buried to such a depth that it may be kept damp by the capillary and hygroscopic moisture of the soil; while, at the same time, it should not be buried so deeply that air cannot gain access to it. Both these considerations naturally point to the conclusion that it will usually be proper to bury manure deeper on light land than on heavy land, though the depth will necessarily vary in different instances, according to the climate and the relation of the soil to the ground-water. It might well be modified accordingly as the season was wet or dry, if the event could but be predicted. It may often happen that a summer shower will moisten the surface soil sufficiently to thoroughly soak the manure there situated, while only the heavy rains of autumn or spring might reach manure that had been deeply buried.

For almost every kind of crop, moreover, there will be some one depth of burying the manure which will be better suited, on the whole, than any other for that special crop; for the roots of different kinds of plants are very unlike, both as regards their bulk or quantity, and their behavior or requirements. Most of the grains, for instance, send out feeding roots in all directions, and so do the different kinds of clover. With carrots and parsnips, or lucerne, for example, there will be little risk of burying manure too deeply.

It would be well for every farmer to determine some of these points once for all for his own soil, by dividing the fields into fractions, and burying portions of the manure at different depths upon the several fractions.

Experiments on burying Manure.

There is an interesting series of experiments bearing upon this point, which were made under the auspices of the Massachusetts Society for Promoting Agriculture, some years since. The idea was to divide a field into five equal parts for a rotation of three years. Four of the plots were manured, but the fifth was not.

The manure on the first plot was ploughed in to a depth of eight inches; that on the second plot to a depth of four inches; and that on the third plot was merely harrowed in, while upon the fourth plot the manure was spread upon the surface of the ground. The results of the experiments have been published, and are well worthy of being carefully studied, though they teach no precise lesson. Doubtless each one of these experiments — and they were made by different farmers scattered throughout the State — must have been exceedingly valuable to the person on whose land it was made, as well as to those neighbors who happened to have land similarly situated.

In these experiments it appears that, in general, deep ploughing (8 in.) answered best for grain, while Indian corn profited most from the manure that was merely harrowed in. Hay did best with manure buried four inches; and, on the whole, so far, be it well understood, as these experiments go, this depth of four inches would

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seem to be the best, in case the farmer were to be compelled to confine himself to any one depth for all crops and soils. Next to 4 in., the depth obtainable by harrowing was found to be best on the whole. In the column of final averages, very little can be found in favor either of deep ploughing or of top-dressing. Even with guano top-dressing has been found inferior to ploughing under.

It is noteworthy in these experiments that the character of the crop seems to have had far more influence upon the results than the character of the soil. For grain, however, the deep-buried manure did best, upon the whole, on the heavy soils; while upon the light soils the shallow-buried manure did better than the deeply buried. Manifestly, the results are complicated by the question whether the ploughing may not have done good in itself. In a few instances, the manure which was spread upon the surface of the light soil did best of all.

In judging of any such experiments as these, the operator will need to view the field with knowledge. That is to say, knowledge as to the position of the ground-water and as to the capillary condition of the soil, as well as of its power of holding rain-water. He will naturally notice also the chemical character of the humus, and whether or not the conditions are favorable for nitrification.

Manure should be well worked in.

No matter at what depth manure is to be buried, it is of importance to secure an equable distribution and dissemination of it in the soil in order that all the plants in the field may be equally well fed and an even stand of the crop secured. Moreover, it is a matter of familiar observation, that, when a lump of manure of any considerable size is buried in the earth, it is apt to remain undecomposed for a long while, and to be found as a lump perhaps even years afterward. It is to avoid this result that farmers take so much trouble to fork over manure repeatedly, and to use it whenever possible in a well-rotted, "short" condition. Various improved harrows, of recent invention, are valuable aids for working manure into the soil evenly and effectively.

Manure may ferment the Soil.

Beside the main points of placing the manure where it can be got at by the roots of plants and kept moist for their sake, there are some other considerations of a chemical nature which bear upon the question of burying manure. Doubtless it often happens that farmyard manure, and other substances rich in organic matter, may do good work by bringing about quick fermentation in the matters of which the soil is composed, whereby the inert nitrogen of the humus, as well as various inorganic substances, are decomposed and made available for the plant. But in order to effect this kind of fermentation, the manure must at the least be covered by the soil. Upon light land, in a dry season, the manure would have to be buried tolerably deep, in order that it shall not dry up and be powerless to induce the fermentations now in question. Here, by the way, is a capital distinction to be made between manure, properly so called, and compost. Composts cannot be expected to excite active putrefactive fermentation in the soil, such as dung would excite.

On the other hand, the formation of nitrates from the nitrogenous components of the manure and the soil is a very important consideration, and it is precisely here that the composts are more likely to do good than the dungs. A well-prepared compost is in some sense a nest of ferment organisms proper to cause nitrification of the humus of the field. The idea is, that as regards nitrification the compost is likely to act more quickly than fresh dung; though the dung might of course favor nitrification after its first hot fermentation is spent.

Leachy Soils.

It is not improbable that the popular opinion that manure should not be buried deeply in light soils is true, because of the property of such soils to facilitate the formation of nitrates from the manure buried in them. It is not probable that such soils are called "leachy" because the ordinary soluble constituents of manure are washed out of them by rain, for the power of the double silicates in the soil to hold these constituents of manure is very great. But within these porous soils nitrates are doubtless formed rather freely, and, as is well known, the nitrates are easily washed out from soils, and are liable to go to waste after every rain that is long continued. They are in fact leached out of the soil, and the manure from which they come rapidly wastes away.

It is said to be a matter of old and familiar observation in Germany, that in sandy regions in seasons that are particularly wet the soil may finally be so thoroughly leached that it becomes unfruitful. Under these conditions tobacco, in particular, according to v. Babo, is sometimes seen to suffer from actual starvation.

On the other hand, it is possible that one reason why manure had better be kept near the surface of light land is that nitrates are formed more readily in that position than at a greater depth; as, for example, in the case of the manure that was harrowed in for corn in the experiments of the Massachusetts Society above mentioned.

Composting the Field itself.

Just as in the preparation of compost heaps, so in the burying of dung there are two tolerably distinct conceptions to be kept in view. Beside nitrification, there needs to be considered the first fermentation, which, when the conditions are favorable, dung may produce, on being buried in the humus of the soil, almost as well as when it is mixed with similar humus in the compost heap. It may often happen that this first fermentation may be produced much more economically by ploughing under dung in the field than by establishing regular compost heaps. In seeking to accomplish this kind of result, the farmer may either plough under fresh farmyard manure, or he may top-dress his grass or fallow land with almost any kind of fertilizer some time before he means to plough, in order to encourage a rank growth of grass or weeds, which, on being turned under, will speedily ferment.

Kinds of Soils fit for Manures.

The views of practical men as to the classes of soils to which one or another kind of manure should be applied, are manifestly based upon considerations such as those just now urged. It is commonly held that horse manure and manure from sheep stables should be applied by preference to cold, clayey loams, or to moist soils rich in humus, where decay will not be too rapid, and where these "hot" manures will tend to warm and enliven the land. Horse manure helps to loosen the land withal, by means of the straw with which it is commonly admixed. On the contrary, the comparatively speaking cold and slowly fermentable cow manure is preferred for warm, light soils, rather than for those that are stiff, or cold, or rich in humus.

It is objected to horse manure on light, sandy soils, that it decomposes there too rapidly, and shows less endurance or lasting effect than is deemed to be desirable. Hence one reason why many practical men think it best, on the whole, not to use horse manure by itself, but rather in admixture with cow manure and the dung of swine.

It is the market gardeners in particular who esteem heavy dressings of horse manure on land moist enough to be well insured against risks from drought. They find their advantage also, in early spring, in making use of the warmth which fermenting horse manure communicates to land upon which early vegetables are to be grown. This point has been studied by Wagner. He found, when the temperature of the air was no lower than 50° F., that the temperature of the soil could be increased to an appreciable degree by working into it stable manure. The warming is specially well marked when the manure is highly nitrogenous, and in a condition fit for rapid fermentation; when large amounts of it are used; and when the soil is not too wet. An addition of materials competent to hasten fermentation, such as barnyard liquor, for example, notably increases the elevation of temperature. So does an addition of lime, though much less emphatically. Most heat is developed immediately after the manure has been buried, though the evolution of heat may persist for some time when the external conditions are favorable. Thus, on land dressed with from 40 to 44 tons of horse manure to the acre, warmth may be imparted to the soil during periods of from 4 to 12 weeks (or more), and the increase of temperature may range from an amount which is barely perceptible to as much as 1° of Fahrenheit's thermometer. On the average, it amounted to from 0°.2 to 0°.7, in these experiments. The best mean increase of temperature for a fortnight was 1°. The maxima of increase observed by Wagner, as imparted to the soil by bean straw (wet with barnyard-liquor?) and fresh horse manure respectively, were 5° and 2°.

One good rule with regard to the burying of manure is, that the aim should be always to fill the staple with plant-food.

Modes of applying Artificial Fertilizers.

What has been said above refers, of course, only to the burying of farmyard manure. In respect to the artificial fertilizers, it can be said tolerably well beforehand what needs to be done in order to secure their proper diffusion and distribution in the soil. For example, superphosphate, nitrate of soda, and even sulphate of ammonia, may be merely scattered on the surface of the land, since they will soak into the soil readily enough. Bone-meal, oil-cake, and fish scrap need only to be buried deeply enough, in not too dry earth, that they may nitrify readily. Bone-ash, bone-black, and phosphatic guano need to be buried pretty deeply, and well commingled with the soil. With them, as with potash salts, it would be well, were it not for the trouble involved, to apply one portion of the dressing before ploughing the land, another before cross-ploughing it, and another before harrowing, to insure thorough distribution.

Why Dung and Urine are Pre-eminent.

There can be very little doubt, after all has been said, that one chief reason why farmyard manure retains so very prominent a position is that people know pretty well how to use it. One strong point in favor of farmyard manure, of course, is the general applicability of it. For inasmuch as such manure contains all the ash ingredients of the plants from which it has been formed, and a fair proportion of their nitrogen also, it is necessarily a mixture of things needed by living plants. More than this, it is a mixture in which the several ingredients are tolerably well proportioned to the demands which will be made by the plants.

It is true, as has been already insisted, that, in one sense, the excrements of animals might seem not to be precisely equivalent in value, as manure, to the food consumed by the animals in producing it. A ton of clover, for example, buried in the ground, might put into the land a considerably larger quantity of fertilizing matter than could be got by feeding out the clover to cattle, and carrying their dung and urine to the field. And instead of "clover," in this statement, the name of any other article of food might be put. In the case of young, growing animals, and that of milch cows or of sheep, the difficulty is aggravated, as has been shown; but in no case is it wholly absent. From numerous experiments made by different chemists, it appears that, on the average, little more than four fifths of the nitrogen consumed by stabled animals in their food can be carried to the fields in the form of liquid and solid excrements. The rest not only serves to form milk, and flesh, and wool, or the like, but the major part of it is dissipated by processes of decay and putrefaction.

Excrement better Manure than Food is.

It was on account of this waste, part of which he wrongly supposed to be due to respiration and perspiration, that Boussingault once remarked: "It is high time that the old notion that cattle produce manure should be done away with. They are really destroyers of manure, — dissipators of manure."

Still earlier than Boussingault, the German chemist Sprengel entertained a similar idea, and he made experiments to prove it.* Starting from the crude notion that the fodder which passes through an animal cannot become "animalized" by the act of thus passing, it was urged that a given weight of food applied to the land as such must produce a greater fertilizing effect than a similar weight of food after it has been fed to an animal, and thereby changed to excrement.

To test this hypothesis, Sprengel fed one parcel of fodder to fatting sheep, and at the same time he prepared a heap composed of another equal parcel of the fodder, to which he applied as much water as was given to the sheep. Naturally enough, his heap of fodder weighed a good deal more than the excrements of the sheep, and on contrasting the two products by applying them for the fertilization of potatoes, the uneaten fodder gave a larger crop than the dung.

Both the remark of Boussingault, and the experiment of Sprengel are interesting and instructive, as exhibiting one view of the subject. But the idea which they seek to express can no longer be accepted as true, in a practical sense. For the chemical constituents of dung are very different from those of plants. Contrary to Sprengel's teaching, fodder *is* "animalized" as it passes through the body, in that the best part of it becomes part and parcel of the body before it is sent out, or expelled in the secretions. Excrements resemble dead flesh withal, in that they afford fit residence for various ferment organisms which bring about decompositions unlike those which occur commonly in the decay of plants.

Dung and urine not only bring to the soil matters directly assimilable by plants, which are of the utmost value as plant-food, but they excite fermentations in the earth, which, as all experience shows, are useful for the growth of plants. Hence, in spite of all the sources of waste above mentioned as incidental to its formation, farmyard manure is a tolerably complete fertilizer. By applying it to the land in sufficient quantity, plants can be supplied with everything necessary for their growth.

As regards the ordinary run of soils, there are few among the commercial fertilizers of which the foregoing remark can be made. Nor is it strange that this should be so, for the commercial fertilizers have come into use as additions to or re-enforcements of stable manure. They originated in countries where the farms are based upon the keeping of cattle, and have found their chief use in connection with stable manure.

Hitherto the artificial fertilizers have, for the most part, been applied in conjunction with dung, to supplement it; or, perhaps even more commonly, some one of them has been put on by itself to force a special crop in a rotation the fundamental basis of which is farmyard manure. It is only comparatively recently that the commercial fertilizers have found extended use in the cultivation of special crops, such as cotton, sugar, and tobacco, and people were singularly slow in grasping the idea that mixtures of the artificial products were needed in order to compete with dung.

Farming possible with Artificial Manures.

It is because of the facts above stated that books relating to practical agriculture still lay so much stress upon farmyard manure, and have so little to say about the practicability of carrying on farms by the exclusive use of commercial fertilizers. Indeed, comparatively speaking, very little information upon this point has ever been published. The experience of many years will be needed, moreover, before any one can say with certainty whether such and such a course is permanently profitable. At the very worst, however, there would seem to be no real difficulty in maintaining a farm in good heart by means of the commercial fertilizers now procurable, if they were used in connection with some system of green manuring, or with composts made of vegetable matters fermented with night-soil, soap-boiler's scraps, or alkali; for in these ways, if in no other, manures of general applicability could be obtained proper to replace the dung of animals.

When the preparation of composts comes to be properly understood and methodized, it may perhaps be found to be true universally, as it is now of cattle farms, that the best way of employing the chemical fertilizers is in small quantities, as helps to the general manure obtained by the decomposition of vegetables.

On good moist land, a little bone-meal, castor-oil cake, cotton-seed meal, nitrate of soda, or superphosphate, used in connection with farmyard manure, will often exert an influence out of all proportion above the cost of the addition.

Use of "Artificials" to produce Dung.

Upon some of the grain farms of Europe it was formerly held that the true theory of the use of commercial fertilizers was, that they should be employed in quantity just sufficient to increase the product of fodder and straw to the extent that a sufficient number of animals might be kept to supply dung enough to manure the farm richly and completely. This theory has merit as far as it goes; but it fails to recognize and allow for a certain deficiency of nitrogen which is inevitable in farmyard manure.

Special Manures sufficient in certain Cases.

There are exceptional soils and districts, so fertile naturally that they do not stand in need of complete manures. Upon some of the intervales of New England, even, and upon reclaimed salt marshes, some one special manure might perhaps be used year after year without exhausting the land. And there are several localities in Europe where potash, at least, seems to be abundantly supplied by the soil. Discretion must, of course, be used in such cases, as always in the application of concentrated manures. But it is to be remembered, on the other hand, that there is no system of farming more unphilosophical, chemically speaking, than that which insists on piling stable manure year after year upon land so rich that the crops grown upon it cannot consume a fair proportion of the food supplied.

According to Lawes and Gilbert it has been found, as a matter of practical experience, upon the highly cultivated grain and stock farms of England, that the amount of mineral constituents immediately available for the wheat crop supplied by stable manure is almost invariably in excess of the supply of nitrogen. Hence the yield of wheat is largely increased on those English lands by the application of nitrogenous manures used in conjunction with the dung, as has already been set forth.

In a similar sense, Rauch, in Bavaria, after having experimented with Peruvian guano for years, came to the conclusion that he could not count with any certainty upon this manure's giving good results unless it was applied to land already in good heart, i. e. land previously enriched with stable manure or with clover sod. The facts being as they are, it is not in the least surprising that the use of a purely nitrogenized manure, like sulphate of ammonia, should have so often given excellent results upon land which had been richly manured for a long time with dung.

It is to be remembered, also, where land is very fertile, either naturally or from having been brought into good condition by careful tillage and abundant manurings, that the annual disintegration and decomposition of mineral matter within the soil will go far to supply the mineral constituents which are taken off in the crops, and that these ash ingredients are of course superadded to those in the dung. Hence it follows, that the special theory of applying commercial fertilizers, to which allusion was just now made, must be modified very decidedly. In many situations, it will be best to use some kind of nitrogenized fertilizer together with the farmyard manure. And if this be done, less stable manure should be applied than is now commonly used. It would evidently be unwise, as a matter of farm practice, to persist in applying large quantities of dung to really good land. A lighter dressing of the dung together with some nitrate of soda, or guano, or fish scrap, or sulphate of ammonia, would usually be better than a heavy dressing of the dung alone.

The recognition by the British farmers of the facts, — 1st, that full crops of wheat cannot be grown unless there be present a liberal supply of nitrogen, as well as an abundance of the mineral matters necessary for the crop, — and, 2d, that upon land which has been highly cultivated for a long time and manured with dung the supply of mineral constituents available for the wheat crop is usually in excess of the available nitrogen, — mark a very important step in the history of agriculture. It is curious to note how, in the light of this knowledge, some of the difficulties which beset the earlier observers are made plain. Thus, to take a single example, Marshall, writing in 1781, is very much exercised concerning a hill of "manure-sick" land which he ran across in his travels. Under date of November 10, he says: —

> "The Bullock Hill at St. Faith's in Norfolk is said to receive no benefit from the droppings of the bullocks, which every year are shown upon it daily during a fortnight or three weeks. This year the land was in wheat; and if one may judge from the stubble, the crop was a very indifferent one, notwithstanding the wheat was dunged for. The soil is a lightish sandy loam."
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> "This interesting fact is said to be due to the worthlessness of the dung of drove bullocks. This I much doubt, however; for the bullocks being many of them in high case, and kept in grazing-grounds about St. Faith's, some of them perhaps within a quarter of a mile of the hill, the driving is little more than the driving of sheep to a fold. Some of the cattle may no doubt come to the hill immediately from Scotland, and they are all of them of course driven more or less, and there may be some truth in this opinion. But upon the whole, it seems probable that driving alone does not produce this interesting fact. May we not venture to think it possible that land may be satiated, or tired, even of the dung of cattle? The hill in question has been the site of a large fair for cattle during time immemorial. Perhaps, were the fair removed and the soil manured with lime, marl, or some such other new manure as experience would point out, it might continue to throw out great crops for many years. This is a subject worth investigating; for

upon old grazing-grounds, which have been fed and dunged with cattle during a length of time, the dung which falls from them cannot on this hypothesis be of any use to the land; consequently the stock may, without injury to the pasture, be driven off in the night-time to fertilize some arable land; or the dung may with advantage be collected and carried off; whilst by mould, ashes, soot, etc., the grass may receive improvement."

It will be noticed that Marshall describes the soil of the hill as a lightish, sandy loam. The inference seems plain, that the nitrogen compounds of the dung had fermented and been oxidized, and that they had been washed away in good part, doubtless in the form of nitrates; and that what the land really needed was a supply of some nitrogenized manure, and, probably, water.

From what is known of the power of soils to retain the mineral constituents of dung, it is impossible to escape the conviction that the soil of this Bullock Hill was highly charged with them. With his usual sagacity, Marshall saw that a new manure was needed. But he did not know that the substance specially indicated was a nitrogen compound, although he mentions soot and vegetable mould, among other things, as fit materials to experiment with. His countrymen have learned the lesson since then.

CHAPTER IV.

SUPERIORITY OF DUNG AND URINE.

Folding and Teathing.

THE foreign practice of applying manure by folding sheep methodically night after night upon the different parts of a field is deserving of special attention in connection with what has been said of methods of saving and applying manure. For, as has appeared already, the sheepfold is one means of bringing manure to the land in the fresh condition, and, in places where circumstances permit this method to be practised, it is esteemed to be a very good way of so doing.

Almost every crop and every kind of soil is said to take kindly to the system. It has, moreover, the reputation of being singularly beneficial to new land, and to land which has never been folded upon. It must be admitted, however, with Marshall, that, "by the term fold, as applied to the fertilizing effect of sheep pent upon land, we do not mean to convey an idea merely of the fæces and urine they leave behind them, but also of the trampling, and perhaps of the perspiration and the warmth communicated to the soil by the practice of folding."

It is not merely the tramping of the ground in the sense of compaction, but the trampling in of the dung, i. e. the mixing of it with the earth, that is to be regarded with favor. It is a matter of history, indeed, that before harrows were invented sheep and swine were habitually employed to trample in seed grain after it had been strewn. The even distribution of the sheep manure is one point to be noted; and another advantage in putting sheep upon stubble-fields is found in the fact that these animals eat and destroy a great variety of weeds which neither cows nor horses will touch.

Still, the chief advantage of folding is found in the fact that all the manure falls upon the land in the fresh condition, and is absorbed by, and distributed in, the soil while fresh. This remark is specially true of the urine, which is put to profit, wellnigh completely perhaps, when it falls upon the soil, as when sheep are folded; but which in the barnyard putrefies and ferments in such wise that a very large proportion of its components are lost in the gaseous form.

It is true of sheep manure, that it is particularly dry and a highly nitrogenized material, which begins to decompose very quickly anyway, and, by thus becoming hot, helps not a little towards its further decomposition and destruction. No kind of manure (unless it be night-soil) stands in greater need of having checks put upon its tendency to decomposition. On contrasting Voelcker's analyses of fresh sheep manure with some that was three years old, it appears that the latter had lost more than 40% of its nitrogen, and somewhat over 60% of its organic matter.

Folding saves Urine.

When urine has been distributed in the soil in the fresh condition, as when sheep are folded, it probably decays in a very different way, even in warm summer weather, from that in which it decays in the dung-heap, and the products of decay, being in presence of an excess of soil, are doubtless absorbed by it in some part. In case, for example, ammonia was formed by the decay of the sheep's urine in the soil, it is fair to assume that little or none of this ammonia could escape into the air. It is certain that no perceptible odor of ammonia would arise from it, such as is evident enough when sheep's urine decays above ground.

As Walz has suggested, the constituents of the urine that has been distributed upon stubble land by the method of folding sheep are commonly put to use immediately by plants, before they have had time to undergo any very complete decay; for they are either taken up by weeds that are growing upon the spot, and are subsequently recovered in the form of a green manuring when the land is ploughed, or some kind of an agricultural crop is sown upon the land that has been folded upon, and in this event the constituents of the urine give an excellent start to the young plants.

In proof that the urine of the sheep is really the most important element in the process of folding, Walz adduces the case where, after sheep have been folded upon a hillside, a sudden heavy shower of rain washes everything movable from the surface of the land, so that the dung is swept away wellnigh completely, and little beside the urine that had soaked into the earth is left to show that folding has occurred. Yet it is a matter of practical experience, that the crops which are grown in due course upon folded land which has been washed clean in this way often yield almost as good harvests as if no washing had occurred.

One advantage in folding sheep is, that there is no expense directly chargeable to the transportation of manure, or to the spreading of it. Moreover, none of the manure can by any possibility be lost between the stable and the field. In a word, there is no "shrinkage." Hence the process has special significance for outlying fields which are distant from the dung-yard, and for hilly, inaccessible pastures. Folding is said to be inadmissible, however, when the sheep are kept for the sake of high grade wool.

Sometimes the sheep are folded on land before the crop is planted, in which event their dung is soon ploughed in; and at other times they are folded after the planting, so that their dung serves as a top-dressing, and their tramping harrows and "rolls" the land, as it were. In both cases, the sheep are usually driven at nightfall from their proper pasture to the land to be manured.

Quantity of Manure from Folds.

In some German works on agriculture, there will be found curious computations as to the amount of land which one sheep will manure in a night, and as to the value of this manuring as compared with that of a dressing of stable manure. Schnee estimates that a good medium manuring, equal to about 100 cwt. of ordinary stable manure, may be got from 2,400 sheep, and that a heavy manuring, equal to about 125 cwt. of stable manure, may be got from 3,000 sheep. Koppe tells, as a matter of experience, that the folding of 3,000 sheep for one night upon 1 Morgen (= 0.631 acre) of poor, thin land, will give a more luxuriant grain crop than four wagon-loads of ordinary stable manure, although 3,000 sheep with their bedding will not produce thus much manure in a night. Hence the cost of folding is offset by the cost of moving the straw and the manure, to say nothing of the waste of straw, which might be used as fodder.

To test this matter, Boussingault folded 200 sheep for a fortnight on rye stubble, in a field of such extent that there should be one sheep to four square feet of surface. The crop of turnips grown on the land thus fertilized was as large as those obtained after the heaviest dressings of farm-yard manure.

Manure from Pastured Cattle.

The droppings of neat cattle at pasture have in general far less economic value than those of sheep, not only because of their compacted condition, which prevents the growth of grass wherever they have fallen, but because of the rankness of the grass which grows around them. In rich pastures, or even perhaps in ordinary pastures which are not too rocky or brush-grown, the droppings may be utilized more or less completely, as is done not infrequently in England, by going over the land occasionally with a flexible chain-harrow,—or perhaps a light smoothing-harrow would answer,—so that the clots of dung may be broken up and the particles distributed.

If a scytheman or a mowing-machine could be spared occasionally to cut down the rank tufts of grass which grow around the clots of dung and where an excess of urine has fallen, it would be well also; for cattle will eat such grass after it has wilted, just as they will eat buttercups, whiteweed, and weeds in general, after they have been mown and are partially dried. It can hardly be open to doubt, that, in pastures good enough and smooth enough to suggest the operation, the cost of running a mowing-machine over the land as often as weeds or waste grass have made head would be amply repaid by the forage that is gained. It is true of many weeds, that the acrid juices which repel animals from the living plants seem to escape by volatilization as the plants become dry.

Quantity of Manure produced in Pastures.

Schnee estimates that the excrements from a medium-sized cow at pasture amount in twenty-four hours to from 37 to 40 lb., or in 165 days and nights to from 6,000 to 6,600 lb. More excrement is passed by day than by night, that which falls by day amounting to 22 to 25 lb. Hence, when cattle are pastured by day and kept up by night, the pasture will receive from 3,600 to 4,000 lb. of manure in 165 days.

These figures are sufficient to give a tolerably good idea of how much a pasture can profit from the droppings of the cattle kept upon it. Furthermore, they go to show why it is that European farmers think so much more of the benefit derivable from pastured stock than our own farmers do.

On those European farms where a cow can be pastured on less than an acre of land, 4,000 lb. of droppings — say half a cord of absolutely fresh dung and urine — may do an appreciable amount of good to that acre. But with us, where two or three acres of pasture — or, sometimes, many more — are needed for the support of a single animal, the manure she furnishes is scattered so widely that no one can see that it has done much good.

Teathe.

The old English writers on agriculture, following a provincial custom, often laid stress on the good effects of the mere breath of cattle upon pasture grass, and upon the benefit which accrues to the grass from the contact of their bodies with it as they sleep by night, — all this beside the effect attributable to the dropping of dung and urine. The word Teathe was used to express this complex idea.

Just as the word "fold" was used to express the fertilizing action of sheep, so "teathe" was used to indicate the fertilizing effect of cattle upon the land upon which they were pastured, or upon which they were foddered with turnips or other food; no matter whether this fertilizing effect is produced by their dung and urine, or by their treading, their breath, their perspiration, or the warmth of their bodies.

A field may be teathed methodically, much as it would be folded. And upon the stock-turnip-grain farms of Norfolk County in England, at the beginning of this century, the practice was wellnigh universal.

Cattle were fatted upon turnips in the field, but the turnips were fed out in such manner that the droppings of the cattle were distributed over the entire field. The farms were laid out, and the crops intermixed, in such manner that each field of turnips should have at least two grain or clover fields in its neighborhood. The turnips were hauled first to the wheat stubble, and there scattered thinly and evenly from the carts, so that the cattle, while eating one turnip, could not tread or dung upon another. The carts began at one side of the field, and worked regularly, day by day, to the other side, giving each part of the land an equal share of the turnips, and never throwing twice in the same place, until the whole field had been gone over. The rule was to keep the turnips about a yard apart.

When the wheat stubble had been gone over often enough to give it a proper supply of manure, the ground was ploughed, and the cattle transferred to barley stubbles. The latter were ploughed in their turn, and from Christmas to April the turnips were thrown upon the clover fields.

This practice of teathing was esteemed to be specially valuable upon light soils, but inapplicable to heavy land or to soils of close texture, — manifestly because of the risk of puddling and tamping the clayey soil.

The teathe of cattle was a merchantable article, like their dung, and it was estimated at a higher or lower price according to the quality of the food and the condition of the cattle. The teathe of heavy, fat cattle was thought to be specially valuable, while that of lean stock and of cows was accounted inferior.

This matter applies, of course, much more particularly to the mild climate of England than to American conditions. The process is described here merely for the sake of an illustration. It was the mild climate, again, which permitted the Yorkshire farmers to teathe their mowing-fields by foddering cattle upon them in winter with hay, as an equivalent for the exhaustion by hay.

According to Marshall, the good effect of feeding out hay upon grass-land that will bear the treading of stock in winter is evident to common observation. There can be no doubt, he says, that in some cases, and under proper management, stacking hay in the field, and foddering with it on the land it grew upon, may be perfectly eligible. On light land, he says, many advantages arise from this practice. The fodder is laid up and the manure applied at small expense. The texture of the soil is improved, and the moss, which is the greatest enemy of land of this description, is checked or destroyed by the treading of the stock.

Nothing of this sort could be done in the cold winters of New England. But it is none the less plain that the custom of teathing goes to show the advantages of using fresh dung and urine. A few words more bearing upon the subject of teathe may here be cited. The famous old writer on rural affairs, Evelyn, says: "The biting of cattle gives a gentle loosening to the roots of the herbage, and makes it grow fine and sweet, and their very breath and treading, as well as soil, and the comfort of their warm bodies, is wholesome and marvellously cherishing." And Hunter, in a note to Evelyn's statement, remarks: "Nice farmers consider the lying of a beast upon the ground, for one night only, as a sufficient teathe for the year. The breath of graminivorous quadrupeds does certainly enrich the roots of grass, — a circumstance worthy of the attention of the philosophical farmer."

Whimsical as these notions now seem to us, it must be admitted that there is no inherent improbability in them. It is a familiar observation, that many varieties of weeds, such as the plantain, mallows, may-weed, and certain grasses, follow the foot of man everywhere. There are probably other plants which frequent the haunts of cattle, and some of them may afford good pasturage. On the other hand, the pressure of the bodies of cattle may be sure death to many undesirable plants.

Teathing with Swine.

An instance of teathing land with hogs on the large scale at a cheese factory in Canada was described in the "Country Gentleman" a few years since. This factory used the milk of 500 cows, and the whey was fed to 100 or 200 hogs. The hogs were kept in a ten-acre lot, preferably of grass land, or land foul with thistles, and the whey was hauled to the field in tanks, from which it was run out through spouts into long troughs. Once in every two or three days the troughs were dragged into new places by means of horses, so that the field was gone over methodically from one side to the other. In this way, the animals were kept healthy; the field was thoroughly manured, and ploughed also by the snouts of the hogs; while the roots of grasses and weeds were pretty thoroughly destroyed. At the end of summer, the land was found to be in excellent condition for winter wheat.

Real Superiority of Dung and Urine.

One important consideration in regard to the action of farmyard manure, as compared with the action of artificial fertilizers, remains to be discussed more fully than has been done hitherto.

If the question were to be asked, squarely, Why is it that farmyard manure continues to be so much more highly esteemed by farmers than the commercial fertilizers are? The reply might fairly enough be made, in words that have been used already, First, because farmers and laborers know very well how to manage dung, while they have still a great deal to learn in respect to the use of the chemical fertilizers. Or we might join in the common cry, and say that dung is superior to the chemicals because it is a tolerably "complete" manure. Or it might be urged, as has often been done by writers, that stable manure exerts a useful physical effect upon the soil, particularly on stiff clays, — an effect such as most artificial fertilizers are incompetent to bring about. Or it may be argued, very properly, that stable manure is of the nature of yeast, in that it contains great stores of microscopic organisms which work to ferment the soil and to make the nitrogen in its humus available for crops.

There is much of truth in each of these assertions, as has been urged on previous pages. They do undoubtedly represent several of the great causes which work to maintain the supremacy of dung.

Then, again, it must be remembered that the great bulk of farmyard manure — no matter how inconvenient and costly this bulk may be as regards the application of the manure — is really of the nature of an advantage, in that it insures a tolerably even distribution of the fertilizing matters, so that every part of the soil becomes charged with them. Hence, as a rule, wherever farmyard manure is applied in quantities large enough to keep the land in good condition, there is really added to the soil a great store or reservoir of plant-food, both in respect to nitrogenous matters and ash ingredients. Moreover, farmyard manure is usually obtained very cheaply, as will be explained in another place.

The Nitrogen in Manure is Superior.

But there is still another reason why farmyard manure retains its supremacy, and it is, in some respects, the most important reason of all. It depends, to all appearance, upon the peculiar condition of the nitrogen in natural manures.

It will be remembered that, beside nitrates and ammonium salts, plants can feed upon various other nitrogenous compounds, such as urea, uric acid, hippuric acid, guanin, leucin, tyrosin, and the like; beside, doubtless, many other compounds which have not yet been isolated and examined.

It is known that urine and dung, i. e. farmyard manures, contain a variety of these compounds, and there is every reason to believe that their presence in natural manures is particularly beneficial for the growth of crops in many cases.

As has been explained in Volume I. of the Bulletin of the Bussey Institution, we are forced to admit the presence of some soluble nitrogen compounds other than ammonia or nitrates in farmyard manure, in order to explain certain familiar facts in respect to the diffusion or soakage of dung liquors in the soil.

As every farmer knows, the earth of any field becomes perfectly saturated with soluble nitrogen compounds to a very considerable depth at the spots where dung-heaps have lain undisturbed for any length of time. Indeed, the places where dung has lain are often unfitted for the growth of useful plants, other than some rank-growing tropical vegetables, such as water-melons or pumpkins.

Now the nitrogen compounds which thus surcharge the soil are evidently not ammonium salts, for ammonia would be fixed near the surface, and could not sink so far into the earth. Nor are they nitrates, for dung liquors are seldom rich in this form of nitrogen. For the present, it is known only that they are soluble organic nitrogen compounds, probably of the same order as some of those whose names have just been enumerated. Perhaps there are several different compounds; but, however that may be, the facts go to show that the nitrogenous dung liquor soaks into the ground with especial ease; that it diffuses itself, within certain limits, in all directions; that it does not decompose very rapidly in cool weather; that plants are particularly fond of it; and that it is not so easily washed out of the land, perhaps, as nitrates are. From all this, it is manifest that, until we can copy this valuable peculiarity of the dungs, our so-called artificial processes of fertilization will labor under one great disadvantage.

The experiments just now alluded to as having been reported in the Bussey Bulletin were as follows. During a couple of years, trials had been made with a variety of fertilizers upon a level field, a part of which had purposely been left bare, in order that it might be used subsequently for another set of experiments. Some of the experiments of the early years required dung, and a place was set apart expressly for the reception and storage of it. But it was found to be impracticable adequately to guard the premises against irresponsible teamsters, and, in fact, several loads of the manure were deposited by mistake upon the fallow land.

Pains were taken immediately to remove this misplaced manure as completely as possible, and the spots where it had been thrown were carefully marked. Finally it was found, when the fallow land came to be planted, that rather better crops grew on the places where the dung had fallen than upon the adjacent land, although this last, as well as the dunged land, had received large dressings of mixtures of phosphatic, nitrogenous, and potassic manures. It was plain that the dung had made itself felt, even when in presence of a large excess of the chemical fertilizers.

Thanks to its easy and even diffusion, and perhaps to its being able to supply nitrogen continuously to the plants throughout the season, or to its being able to supply nitrogen in some peculiarly favorable form, the dung did unquestionably exhibit a kind or form of power which the commercial fertilizers lacked.

Of course, an experiment such as this goes far to justify and support the prejudice of practical farmers, that dung is really a better manure than the plants from which it came. It goes to show withal, and that emphatically, that the ploughing in of a green crop may be a very inferior method of manuring, as compared with the common system of transforming the crop to dung by means of cattle, and then putting the dung upon the land. But if this inferiority be real, a fatal blow is struck at Boussingault's dictum that cattle are dissipators of manure; and we are compelled to accept with but little reservation the old and widely spread prejudice, that there is nothing like dung and urine.

Guano similar to Dung.

The question arises immediately, Is there not among all the commercial fertilizers any one, or perhaps some mixture of several, which can be classed with farmyard manure in respect to this useful diffusibility of nitrogen?

Yes; there is one, and that is the so-called rectified guano, — "unlocked guano," the Germans call it, — i. e. Peruvian guano which has been treated with sulphuric acid. Undoubtedly the original Peruvian guano deserves to be classed in the same category; but, in the experiments here to be cited, the rectified guano approved itself so particularly that it will perhaps be best to dwell upon it rather than upon the unimproved raw material.

In one word, it may be said, however, that the most dung-like of all the commercial fertilizers is the one best fitted to compete with farmyard manure. It will be observed, that in this fact we have the strongest possible indication of the truth of the dictum that it is the peculiar nitrogen compounds in farm manure that give it its special power. Nothing can be more significant of the fact that this nitrogen is really the efficient cause, than the other fact, that, in seeking to compete with the dungs, experimenters have been forced at last, after trying all other kinds of nitrogenized fertilizers, to rest contented with what is really another kind of dung; or, at the least, the experimenters have brought up at a product obtained by the chemical treatment of the bird dung (guano) with acid.

As is well known, guano contains, beside ammonium salts, a quantity of uric acid, some guanin, and small amounts of various other nitrogenized organic matters, all of which doubtless have a somewhat different action upon vegetation from the ammonium salts. Guano is, in short, one of the most complicated of all known fertilizers.

About half the nitrogen in guano is in the form of ammonium salts, while the other half is in the form of the organic compounds just spoken of; and among these organic compounds uric acid is the most abundant. The true original Peruvian guano, that contained some 12 or 13% of nitrogen, contained as much as 10 or 15% of uric acid in combination with ammonia, as has been seen.

The chemical composition and the behavior of uric acid are tolerably well known, and the same may be said of guanin also; but of the other nitrogenized matters which occur in small proportions in guano next to nothing has been ascertained hitherto. Chemists are ignorant as to the composition of these things, and as to their relations to other chemical substances. It is not known in the least how they behave when treated with sulphuric acid, for example.

As for the action of sulphuric acid on uric acid, it may be that some of the uric acid is changed thereby to a more soluble substance, though the supposition is rather improbable. It was urged at one time, that some of the uric acid is changed to ammonia when guano is acted upon by sulphuric acid. But Grouven denies this, and

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says that he finds very little more ammonia in rectified guano than in crude guano.

At first sight, the chances would seem to be that the uric acid in rectified guano must come to the earth as such, — much as would have been the case if the original crude guano had been applied to the land, — and that the only beneficial action of the sulphuric acid treatment is to make the phosphoric acid in the guano soluble. But, as will be seen directly, there is some evidence that works against this supposition. It may be true, after all, that the sulphuric acid does good simply by killing the microdemes in the crude guano, and thus hindering the uric acid from fermenting when the guano is mixed with the soil. It is not at all improbable that uric acid can thus be preserved from decomposition for a considerable period of time, and so kept in fit condition to play its own peculiar part for helping the growth of crops. This idea is strengthened by the fact of observation, that guano when admixed with a germicide substance, such as common salt, often does particularly good service as a fertilizer.

The first scientific inkling of the real superiority of guano over artificial mixtures of the so-called chemical fertilizers was got by the German chemist Grouven, who subsequently studied the question in some detail.

In 1862 Grouven had a number of field experiments with fertilizers carried out on the large scale, upon twenty different farms in various parts of Germany. On comparing the results of these experiments, he was struck with the fact that, as a rule, the mixtures of ammonium salts and superphosphates, and of nitrate of soda and superphosphates, that had been employed, failed to answer so good a purpose in respect to the crops harvested as rectified guano, although it had been proved by analysis, at the start, that the mixed fertilizers used contained amounts of nitrogen and of soluble phosphoric acid that were equivalent to those in the rectified guano.

Grouven published some remarks upon this point at the time, and dwelt upon the noteworthy circumstance that the sale of rectified guano was steadily gaining ground in Germany, as it had been for some little time previously, in spite of constant efforts on the part of the manufacturers of fertilizers to compound a mixture artificially which should be equally good with the guano. So long ago as 1872 a large proportion of all the guano imported into Germany was treated with sulphuric acid before it reached the farmers' hands.

In order to be perfectly sure of the facts, as above stated, Grouven repeated his experiments in a very thorough way. He had a number of trials carried out during four years by several different farmers of repute, to whom he furnished fertilizers that had been analyzed after very careful preparation. These fertilizers were designated by numbers merely, so that the actual experimenters — the farmers to whose land they were applied — had no precise knowledge of what they were using, and consequently could not have had any very forcible bias in favor of either one of the mixtures.

The following table of averages, taken from the great mass of Grouven's results, will illustrate the general position of guano in comparison with the positions of other manures. It will be seen that the action of the guano is allied to that of the dungs, and that it is superior to that of the simple superphosphates, nitrates, and ammonium salts.

INCREASE OF CROP PER HECTARE OVER THE UNDUNGED FIELDS.

(1 centn. beets = ⅓ thaler; 1 centn. oats = 2 thalers; 1 centn. straw = ⅔ thaler.)

Manure per Hectare in 1862. (1 centn. = 50 kilos.)	1862. Sugar Beets. Average of 20 Fields. Thalers.	1863. After effect of the Manures. Oats and Straw. Average of 13 Fields. Thalers.	1864. After effect of the Manures. Beet Roots. Average of 12 Fields. Thalers.	Cost of the Manures per Hectare, in Thalers.
700 centn. cow dung . .	54.4	20.8	35.6	72
700 " horse dung . .	67.6	30.4	58.0	80
700 " sheep dung .	84.4	38.4	55.2	90
6.3 Peruvian guano . .	50.8	11.6	15.6	30
12.6 " " . .	71.2	16.4	16.0	60
25.2 " " . .	95.2	30.8	31.6	120
15.6 superph. à 13 % . .	35.2	5.2	31.2	34
31.2 " " . .	42.4	5.2	35.6	68
6.3 sulphate of ammonia	19.6	0.0	0.0	36
12.6 " " .	46.0	4.0	0.0	72
5.9 nitrate of soda . .	34.8	2.8	0.0	34
11.8 " " . .	56.8	5.2	0.0	68

All the dungs, fertilizers, and seeds came from one and the same source. The sowing and harvesting were done on the same days, and the plan of all the experiments was the same.

Of course it would be natural, in so far as this table alone goes, to explain a good part of the differences by falling back upon the fact that guano, like the dungs, is a tolerably complete manure, while the superphosphates and the nitrogen compounds are special manures, and altogether one-sided; but, as will be shown directly, this explanation is wholly insufficient.

As confirming Grouven's results, the following table, drawn up by Stoeckhardt, may be cited. It was published in 1862 as a compilation from all the field experiments on sugar beets that had been reported during several preceding years.

Peruvian guano gave better crops than nitrate of soda in	11	out of	22	experiments.
Better than ammonium salts in	9	"	10	"
Better than bone-meal in	25	"	40	"
Better than superphosphate in	23	"	32	"
Better than rape-cake in	20	"	28	"
Better than cow and farmyard manure in	14	"	17	"
Better than horse manure in	6	"	12	"
Better than urine or barnyard liquor in	13	"	18	"

These results, as well as those obtained by Grouven, are tolerably emphatic. But at the time of these trials, as Grouven reports, the reproach was constantly made that the use of guano alone must be injudicious. It was urged, that the guano contained too much nitrogen in proportion to its other ingredients; that it was consequently one-sided, and must inevitably tend to exhaust the land. It was argued that it is too uncertain, especially in dry years, and too costly. The advice was repeated upon every hand that guano had better be used in conjunction with other, cheaper, fertilizers, such as the superphosphates, bone-meal, and potash salts, or even with ammonia salts, or with nitrate of soda, so that no more than half the cost of manuring a field should be spent upon guano.

Among other receipts, the following were often recommended, viz.: half guano and half potash salts; also one third guano, one third potash salts, and one third superphosphate; so, too, mixtures of guano and sulphate of ammonia, and of guano and nitrate of soda, were recommended as powerful forcing manures; and it had been claimed at one time or another for all of these mixtures that they were surer and more profitable than guano alone.

Grouven proceeded to put some of these suggestions to the test of experiment. Like most, if not all agricultural chemists, he had believed *a priori* that many such partial substitutions as the foregoing would really be more rational than the use of guano alone. It is probable that his real purpose in trying the mixtures was to find which among them was the most efficient.

He tried mixtures in which one third or one half of the guano had been replaced by two other fertilizers of equal cost with the guano that had been removed. His results were as follows:—

Year.	No. of Fields of from 1 to 1½ Hectares.	No. of Comparisons with Guano.	No. of Results that were favorable for the Guano.
1861	10	20	18
1862	24	72	46
1863	13	39	31
1864	12	36	21
1865	8	40	27
1866	13	91	39
1868	11	44	27
1869	16	16	7
1871	7	28	22
1872	3	3	2
Sum	117	389	240 = 62%

That is to say, of 389 experimental plots on 117 different fields there were 240 results favorable to the use of simple guano. There were only 38 results in a hundred where the guano alone yielded smaller crops than the mixtures of guano and other fertilizers.

Of course, this result applies to rich German lands, and doubtless to lands that were more evenly and abundantly supplied with moisture than most New England soils, for example.

There is nothing in the results to dissuade us Americans from using potash salts with guano, or from using guano in small quantities as an addition to other manures. But as an illustration of the peculiar attribute of guano now under discussion, the results are not a little remarkable.

It may be said, indeed, that the table really means more than Grouven claimed for it, since it shows so well the peculiar efficacy of the nitrogenous matters in guano when added to good strong land, such as the best fields of Germany are.

The soil of the fields where these experiments were tried was naturally rich and strong. It needed an excitant rather than a mixture of fertilizers; and the results given in the tables show that guano and the dungs afforded the necessary nitrogenous excitation.

Next in order come experiments in which plain guano and rectified guano were contrasted. The following table relates to sugar beets. Each plot got 47 thalers' worth of fertilizer. The crops are the means obtained from thirteen different fields, each one hectare in area.

1866.	Unmanured.	360 Centn. Best Stable Manure.	10 Centn. Crude Peruvian Guano.	10 Centn. Rectified Guano.
Excess of crop (washed roots) over the unmanured . .	. . .	46.0 centn.	85.0 centn.	103.0 centn.
Per cent of sugar in the juice	13.7	13.5	13.6	14.1
Degrees marked by Brix's hydrometer	16.4	16.3	16.8	16.6
Other matters besides sugar in the juice, per mille .	27.0	28.0	32.0	25.0
Increase of sugar over the unmanured	. . .	6.2 centn.	11.5 centn.	14.5 centn.

Here is a marked increase of crop in favor of the rectified guano, as compared with the crude; and the result was true, not merely for the average of all the cases, but for the greater number of cases as well. And it is remarkable that the rectified guano was so much better than the crude, in spite of the fact that the 1,100 lb. of crude guano which were used to the hectare (440 lb. to the acre) contained one fifth more nitrogen, and one fifth more phosphoric acid than were contained in the same weight of the rectified guano.

The rectified guano crops gave a much purer juice withal. They contained more sugar and less saline matter than the others. But a pure juice like this is a great gain for the sugar-maker, since in the absence of salts and other impurities the sugar crystallizes out more readily and more completely. Even the undunged fields, which are commonly held to yield the purest sap, gave results which were inferior in this respect to the fields that had been dressed with the rectified guano.

This result is remarkable from the scientific point of view, and may perhaps lead eventually to a clearer understanding of how and why it is that plants take in the unnecessary salts.

Grouven remarks, that, while no fertilizer or mixture of fertilizers known to him has in general so beneficial an effect upon the quality of beet juice as rectified guano, no such effect can be attributed to crude guano. On the contrary, the tendency of crude guano is, if anything, to injure the quality of beet juice.

From this fact, Grouven draws the inference that the action of sulphuric acid upon guano must be in reality more emphatic than any one would have been disposed to believe *a priori*. He argues, that no mere change, such as the fixing of the ammonia in the guano, or the rendering of its phosphoric acid soluble, can be supposed to produce a physiological effect upon the beet root so striking as this alteration of the juice. But, as was suggested before, it is not impossible that the sulphuric acid, by destroying ferment germs in the crude guano, may hinder its uric acid from changing either to ammonium carbonate or to nitrates, and so permit the uric acid to feed crops in its own peculiar way during a considerable part of their terms of growth.

Grouven next proceeded to contrast rectified guano with certain so-called substitutes for it that had been thrown upon the German market in large quantity. One of these guano substitutes was a mechanical mixture of 50 lb. of sulphate of ammonia, with about 9½ lb. of nitrogen, and 50 lb. of Baker Island superphosphate, with about 9½ lb. of soluble phosphoric acid; while another (less common) was 62 lb. of nitrate of soda, with about 9½ lb. of nitrogen, and 50 lb. of Baker Island superphosphate, with 9½ lb. of phosphoric acid.

Of the first of these mixtures 100 lb., and of the second 112 lb., were very nearly chemically equivalent to 100 lb. of the rectified guano with which they had to compete.

It will be noticed that Grouven leaves the potash in the guano entirely out of the account, which is unfortunate for the New Englander, since he cannot escape the conviction that it must have had a certain amount of beneficial action. It is to be remembered, however, that many, if not most, of the rich German soils contain an abundance of potash, and that there was a mass of farm experience to justify Grouven and the makers of fertilizers in neglecting potash. In the experiments where crude guano and rectified guano were contrasted, there was of course more potash in the crude than in the rectified material.

As for the guano substitutes just spoken of, the cost of either of them was very nearly the same as the cost of rectified guano, at the time when Grouven made his experiments.

CENTNERS OF POTATOES PER 1 HECTARE, MEANS OF 11 HARVESTS FOR 1867.

360 Centn. Stable Manure.	7.1 Centn. Nitrate of Soda + 5.6 Centn. Superphosphate.	5.6 Centn. Sulph. Ammonia + 5.6 Centn. Superphosphate.	10 Centn. Rectified Guano.
331	374	373	381

Since the average yield of all the manured plots was 303 centners of potatoes, it appeared that the increase was 28, 71, 70, and 78 centners, respectively. Moreover, the potatoes from the rectified guano fields were somewhat richer in starch than those from the other fields.

Centners of Potatoes per 1 Hectare, Means of 15 Harvests for 1869.

	No Manure.	5.3 Centn. Sulph. Ammonia + 5.3 Centn. Superphosphate.	7 Centn. Nitrate Soda + 5.3 Centn. Superphosphate.	470 Centn. Stable Manure.	10 Centn. Rectified Peruvian Guano.
Mean total harvest	304	349	353	364	369
Mean increase . .	...	45	49	60	65

Means of 7 Harvests for 1871.

No Manure.	360 Centn. Stable Manure.	3.1 Centn. Sulph. Ammonia + 7.8 Centn. Superph.	3.5 Centn. Nitrate Soda + 7.8 Centn. Superph.	7 Centn. Rectified Guano.
227	248	252	262	282
...	21	25	35	55

For 1872.

Trial No.	No Manure. Centn. Potatoes.	4.9 Centn. Sulph. Ammonia + 5.3 Centn. Superph.	9.4 Centn. Rectified Guano.
1	84	141	181
2	235	323	332
3	289	430	380

Grouven very justly remarks, that the reader must not be deceived by the absolute smallness of the numbers as here cited.

Since the figures are the means of many experiments, — some of which were of no account either way, and some of which gave results that were contrary to the majority of the results, — they can hardly fail to be small. But they nevertheless represent the real superiority of the rectified guano.

Moreover, it is a fact, that, out of 36 different fields, the rectified guano gave decidedly better results in 24 instances than its ammoniacal competitors. That is to say, the guano gained the day in two out of every three of the trials.

So too, out of 33 fields where the rectified guano was put in competition with mixtures of nitrate of soda and a superphosphate, the guano excelled in 22 instances, or two times out of three, again.

Taking the whole 46 cases (24 + 22) where the guano gave the best results, it appeared that the average excess of crop due to the guano, over and above what was yielded by the substitute, was 3,322 lb. of potatoes per hectare. But, on the other hand, in the 23 instances (12 + 11) where the substitutes for guano gave the best crops, it appeared that the gain over the guano was no more than 2,684 lb. of potatoes per hectare.

Or, to sum up, the rectified guano was better than the proposed substitutes in two thirds of all the trials, and produced on the average some 1,300 and odd pounds of potatoes more per acre than the equally costly substitutes.

It might be said, indeed, by some persons, that, although the foregoing statements may be true enough as regards potatoes, they might not hold true for grain. But the burden of proof would lie upon whoever was bold enough to make such a suggestion as this; for it is well known that guano is an excellent application for grain, and that the more thoroughly a manure can diffuse itself into all parts of the soil, so much the better will the grain crop be suited; and, as Grouven urges, it is precisely this power of rapid and useful diffusion which makes the rectified guano a better fertilizer than the substitutes.

The objection would, moreover, have been refuted by the fact, that by far the larger part of the rectified guano sold in Germany at that time was used upon grain crops.

Grouven cites the following experiments as illustrating this fact of useful diffusion. Two loamy fields, that had not been manured for five years, were divided into plots of 1,900 square feet. Barley was grown upon one of these fields one year, and the year after wheat was grown upon the other. The results were as follows: —

1857. 1st Field. — Barley.	The Manure contained of Nitrogen.	of soluble Phosph. Acid.	Harvest. Grain.	Straw.
	lb.	lb.	lb.	lb.
No manure	. . .	. . .	13.6	36.7
13.4 lb. phosphate of ammonia	2.8	7.2	14.6	36.0
20 lb. guano	2.8	2.6	34.4	66.6
1858. 2d Field. — Wheat.				
No manure	. . .	. . .	36.2	65.9
11.9 lb. phosphate of ammonia	2.5	6.4	43.0	77.9
18.8 lb. guano	2.5	2.4	65.9	158.0

The upshot of the matter is, clearly, that the nitrogenized constituents of the guano do better service than the nitrogen of the ammonia compounds and the nitrates; or, rather, that they do a certain kind of service which the ammonia salts and the nitrates are unable to perform.

Both the ammonium salts and the nitrates are well enough as far as they go, and it may perhaps be true that the ammonia salts in guano do as much good as either of the other nitrogenous constituents which the guano contains, or even more. But there is evidently some substance in guano, and in animal excrements in general, which helps and reinforces the ammonia salts.

Guano with Sulphates.

Some experiments may here be cited in which mixtures of guano and gypsum, or guano and Epsom salt, gave good results when contrasted with mere guano. These results may perhaps eventually help to explain the superiority of rectified guano, although their full meaning cannot as yet be seen. Krocker made experiments on oats and on wheat, as follows: —

OATS ON A CLAY SOIL.

On a Morgen (= 0.681 Acre) of Land.	Crop. Grain.	Crop. Straw and Chaff.
1 cwt. of guano	420	2,880
1 cwt. of guano treated with 5 lb. of sulphuric acid	440	3,000
1 cwt. of guano and 1 cwt. of gypsum	560	3,340
OATS ON SANDY LOAM.		
1 cwt. of guano	608	2,332
1 cwt. of guano and 5 lb. of sulphuric acid	646	2,643
1 cwt. of guano and 1 cwt. of gypsum	773	2,645
WHEAT ON A CLAY SOIL.		
1 cwt. of guano	815	2,030
1 cwt. of guano and 5 lb. of sulphuric acid	880	2,310
1 cwt. of guano and 1 cwt. of gypsum	970	2,370

These results go to show that the good effect of the rectified guano cannot depend solely on the existence in it of soluble phosphoric acid. Moreover, it can hardly be true that the action of the gypsum to set free potash from the double silicates in the soil is the sole cause of the increase of the crops, for some gypsum was, of course, formed by the addition of sulphuric acid to the guano, as stated in the second line of each division of the table.

Hellriegel urged that sulphate of magnesia mixed with guano would decompose its ammonium salts, with formation of non-volatile sulphate of ammonia, which is less subject to decomposition than the urate and oxalate. Experiments on winter rye that were made at his suggestion gave the following results: —

	Grain.	Straw and Chaff.
No manure	448	1,328
1 cwt. guano	544	1,688
1 cwt. guano and 10% sulphate of magnesia	572	1,656

In another locality the results were as follows: —

1 cwt. guano	356	1,294
1 cwt. guano and 10% sulphate of magnesia	447	1,627

The Merit of Dung-nitrogen should be recognized.

Although it is not yet known precisely how or when the organic nitrogen compounds in dung or guano do their work in the soil, the fact of such ignorance should not deter any one in the least, either from recognizing that a peculiar kind of work is done, or from allowing for it as a practical force.

The chances are, that the merit of the dung or guano nitrogen depends not only on its being evenly distributed in the soil, but also upon its offering food to the plant sucessively, continuously, and by instalments. As has been said, ammonium salts are liable to be fixed by the soil too near the surface, and to be changed more or less speedily to nitrates and to inert humus; while the nitrates tend to be washed out of the soil altogether.

Guano (and Dung) a very intimate Mixture.

Another thing to be said is, that artificial mixtures of fertilizers can never be made so intimate as the guanos and dungs are naturally. The smallest kernel of guano, like all the other kernels, large or small, contains, namely, a great variety of fertilizing matters. But when a mixture of an ammonium salt and a superphosphate is scattered abroad, or when the two substances are applied to the land one after the other, there will inevitably be left great gaps and interspaces between the unlike particles when they fall upon the ground.

The futility of trying to copy guano precisely has been urged by Dr. Voelcker in the following terms. Take the case of milk, he says; we know the composition of milk far better than we know the composition of guano. But the best mixture we can make of casein, sugar, butter, ash ingredients, and water, all in the proper proportions, can hardly be called milk, and no one would expect such artificial milk to produce precisely the same physiological effect as real milk. And so it is, he goes on to say, with our substitutes for guano.

The old Humus Theory an Expression of the real Merit of Dung.

It was probably from observing the great, and, as is now known, the peculiar, fertilizing power of barnyard liquor, — which they not unnaturally regarded as a solution of humus, — that the older agriculturists were led to attach an exaggerated importance to humus, considered as a kind of plant-food. Indeed, the so-called humus theory, which for many years was a prominent article of faith among agricultural writers, probably depended in good part on this observation, and on the palpable fertilizing power of well-rotted dung. When, for example, Hlubeck said that "the extract from rotten organic remains forms the proper nourishment of plants, and that it is more efficacious in proportion as it has come from a variety of animal and vegetable substances," it seems plain that he must have been thinking of the drainings of dung-heaps. So too the favor in which thoroughly rotted dung was held probably depended in part on its looking like humus; while, conversely, much of the credit so long accorded to humus may justly be attributed to its looking like rotted dung. The habitual use by New Englanders of the word "muck" as a synonym of bog earth is manifestly an expression of this idea.

Few Commercial Fertilizers diffuse readily.

One of the limitations to which most commercial fertilizers are subject was clearly indicated at the Bussey Institution on seeking to recuperate with chemicals a field of rather poor land, after a variety of experiments had been made upon it during a term of years with special fertilizers. It then appeared that it was no easy matter to mix some of the artificial fertilizers properly with the soil.

Excepting superphosphate of lime and nitrate of soda, the fertilizers appeared to be fixed for the most part where they fell upon the exhausted soil; and it seemed as if the subsequent crops had to struggle with streaks and seams of poor soil interspersed with streaks of soil that were over rich in respect to one or another kind of fertilizing agent. These results went to show that the ploughing in of green crops may have real merit as a means of refreshing worn-out soils, considered merely as a means of distributing the fertilizing matters, or rather of putting them where they will do the most good.

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CHAPTER V.

NIGHT-SOIL.

As has been set forth already, there can be no doubt that fresh human excrements are richer in fertilizing matters than those of farm animals. The food of man is commonly much more concentrated than that of animals. It is richer in respect to nitrogen and phosphates, and, as analysis shows, the excrements derived from such food are correspondingly concentrated and valuable. Contrasted analyses of various dungs and urines have already been given in Volume I., and it would be easy to cite a considerable list of similar determinations. According to Wolff, the average composition of human excrements is as follows: —

	Water.	Organic Matter.	Nitrogen.	Phosph. Acid.	Potash.	Lime.	Magnesia.
	%	%	%	%	%	%	%
Fresh human fæces	77.2	19.8	1.0	1.10	0.25	0.62	0.36
Fresh human urine	96.3	2.4	0.6	0.17	0.20	0.02	0.02
Mixture of the two	93.5	5.1	0.7	0.26	0.21	0.09	0.06

As ordinarily procurable, night-soil is far from containing so large a proportion of fertilizing matters as fresh excrement, because of the fermentations and leachings to which it is usually subjected, and because of its liability to be mixed with water and with other diluents, such as ashes and other rubbish. Indeed, one strong objection to the use of night-soil, as obtained at random from a town or city, is its great liability to variation. The farmer can seldom be sure as to the real value of any given load of it, — not nearly so sure as he would be in the case of horse manure or cow dung.

Some conceptions as to the average composition of good night-soil, as taken from vaults not subject to leaching or dilution, may be got from the following table of analyses.

ANALYSES OF NIGHT-SOIL (MOSTLY LIQUID) FROM VAULTS.

	Water.	Organic Matter.	Nitrogen.	Phosph. Acid.	Potash.	Lime.	Magnesia.
	%	%	%	%	%	%	%
Quesnoy (near Lille?), Girardin (not diluted)*	96.04	2.66	0.92	0.88	0.21	. . .	. . .
Ditto, from a large factory, much diluted with water* .	99.65	0.05	0.18	0.08	0.02	. . .	. . .
Lille, from a dwelling-house, diluted with 12-15% water*	98.86	0.54	0 67	0.10	0.15	. . .	. . .
Paris, L'Hôte †	98.12	1.28	0.44	0.14	. . .	0.16	. . .
Munich, mostly liquid . . .	95.51	2.01	0.18	0.26	. . .	. . .	. . .
" thick liquid . . .	90.52	7.85	0.69	0.52	. . .	. . .	. . .
Karlsruhe, from a large public collecting vault (Nessler) .	96.00	3.00	0.40	0.12	0.17	. . .	. . .
Cassel, public vault into which tubs from private houses were emptied (Nessler) . .	. . .	. . .	0.8-1.0	. . .	. . .	. . .	. . .
Stuttgart, from a public collecting vault (Wolff) . . .	94.0-96.0	1.51	0.43‡	0.15-0.19	0.18-0.21	. . .	. . .

* The first specimen contained 0.76% of ammonia; the second, 0.21%; the third, 0.57%; all with traces of nitrates.

† This specimen contained 0.52% of ammonia. The average of 12 different samples was 0.87% of nitrogen, the amount having ranged from 0.25 to 0.69%.

‡ 3.69% as ammonia and 0.6% as organic nitrogen.

	Water.	Organic Matter.	Nitrogen.	Phosph. Acid.	Potash.	Lime.	Magnesia.
	%	%	%	%	%	%	%
Stuttgart, thicker	96.40	...	0.54	0.20	0.27	...	...
Groningen, average, mostly liquid (Fleischer)	97.10	...	0.29	0.01	0.36	...	...
Bremen, average, solid and liquid (Fleischer)	81.70	...	0.52	0.51	0.26	2.71	...
Average composition of night-soil from cities, mostly liquid (Wolff)	95.50	3.00	0.35	0.28	0.20	0.10	0.06

In some parts of the world, notably in China, Japan, and Belgium, human excrements are highly esteemed and largely used as fertilizers. But it is noteworthy, that little or no repugnance is there felt with regard to the storing, transportation, and manipulation of the material; and it is certain that the processes customary in those countries would not be tolerated in countries more keenly alive to considerations of decency, comfort, and health.

Repugnance of English-speaking Races to Night-soil.

In England and America, most persons, farm laborers included, regard the emptying of cesspools, and even the application of night-soil to the land, as loathsome and degrading drudgery, to be avoided whenever possible; and there can be no question that this repugnance is justifiable and commendable when not carried to extremes. That the feeling marks a certain progress in refinement, and in civilization even, cannot be gainsaid. All practices which tend to destroy the self-respect of the persons that engage in them are manifestly out of place in civilized communities. From the accounts of travellers in China, it is evident how exceedingly offensive the manipulation of night-soil may become whenever the agricultural belief in its efficacy is generally diffused in a given locality, and is permitted to override other considerations.

Undoubtedly the repugnance of the English-speaking races to have any dealings with night-soil is one prominent reason why this substance has played so small a part in the development of English and American agriculture. But it is not the only reason, for, as was just now said, the contents of cesspools that have been left for some time to themselves undergo fermentations of such character that the matter loses a very considerable part of its value. Much of the nitrogen, especially, is apt to fly off, and leave the residual substance so much the poorer; and, as has been said, old night-soil is liable to be rather poor stuff any way.

Moreover, night-soil is a less complete manure than the strawy products ordinarily obtained in the farmyard. Indeed, it was objected to formerly because of its forcing character and supposed tendency to exhaust the land. This difficulty could readily be met nowadays by using appropriate artificial fertilizers, notably potash compounds, in conjunction with the night-soil. Some farmers near Boston have found their advantage in using night-soil together with strawy horse-manure; for the two kinds of manure supplement each other in some part as regards chemical composition, and the odor of the horse dung masks that of the night-soil.

Undue Praise of Night-soil.

It is a curious fact that, in spite of the unwillingness of Englishmen and Americans to handle night-soil, many people in both countries entertain highly exaggerated views with regard to the money value of it. Formerly it was much the fashion also to attach undue values to poudrette and other products prepared from night-soil. Far too much stress used to be laid withal upon the fact that there were formerly several cities in Europe — notably, Strassburg, Lyons, Antwerp, Ostend, and several other Belgian towns, in regions given over to the old Flemish system of using liquid manures — that received considerable sums of money from contractors who removed the night-soil and sold it as manure, instead of having to pay out money in order that the night-soil should be removed. This matter turns of course upon the estimation in which night-soil is held by the farmers in the immediate vicinity of the city, and there is a wide diversity of opinion in different localities.

In most cities of Continental Europe, however, the removal of night-soil and sewage is a bill of expense, as it is in England and America. Taking the whole civilized world into consideration, less and less use is made of human excrements every year, and the cost of getting rid of the filth of cities tends continually to increase. At Boston, it must be admitted that night-soil is a very cheap source of nitrogenous, and even of phosphatic manure, for those farmers who care to use it. Market gardeners, in particular, so situated that they can readily dilute the material with water and apply the diluted liquid to crops, would probably find their advantage in building special reservoirs for its reception.

Sanitary Considerations take Precedence.

In reality, the price which a city may obtain for night-soil is not a question to be seriously considered. The fact that a city expends no money for removing night-soil, or that it gains money by the sale of it, cannot for a moment justify the maintaining of vaults and other abominations in its midst. From the point of view of the citizen, it is in terms of health and of comfort that the problem must be considered, and not in terms of money. It matters not what the night-soil of a city may be worth, so long as sanitary considerations require that the offensive material should be immediately diluted with such an enormous bulk of water or earth that the recovery or utilization of the fertilizing ingredients would cost more labor or carriage than they are worth.

Estimated Value of Excrements.

Several chemists have computed how much plant-food is contained, on the average, in the solid and liquid excrements of a man in a day and in a year. The following table, from Heiden, which is based on a large number of analyses, refers to the average inhabitant of a city, excluding children less than five years old. The weights in the columns headed "Year" are pounds avoirdupois.

	In Solid Form.		In Liquid Form.		Total.	
Amount produced.	Day.	Year.	Day.	Year.	Day.	Year.
	grm.	lb.	grm.	lb.	grm.	lb.
Excrement . . .	133.0	107.0	1,200.0	964.0	1,333.0	1,071.0
Dry matter . . .	30.0	24.4	64.0	51.4	94.0	75.8
Organic matter . .	25.5	21.8	50.0	40.2	75.5	62.0
Nitrogen	2.1	1.7	12.1	9.7	14.2	11.4
Ashes	4.5	3.9	14.0	11.0	18.5	14.9
Phosphoric acid .	1.4	1.1	1.8	1.5	3.2	2.6
Potash	0.6	0.5	2.3	1.9	2.9	2.4

Allowing that the nitrogen is worth 18 cents the pound, and the phosphoric acid and potash 5 cents the pound each, the yearly value of the excrement of a single person would be $2.25, supposing it were possible to put the excrements to immediate use. On multiplying this sum by hundreds of thousands or a million of inhabitants, or even by several millions, as has been done again and again in the case of London, figures are obtained of enormous magnitude; and many persons have been led to believe at one time or another that some part of these calculated values might actually be realized. Numerous, and in several instances thoroughly well-considered efforts, have been made to accomplish this result; but, with some trifling and limited exceptions, such schemes have invariably failed.

As will be seen from the table, so large a proportion of the weight of human excrements consists of inert and worthless matters, to begin with, that, at the very best, night-soil cannot possibly bear the cost of transportation, even for moderate distances; and, as will be shown directly, it is no easy matter, economically speaking, to recover any part of the valuable constituents from a material which contains so small a proportion of them, and which is so offensive to manipulate.

The large proportion of water naturally contained in human excrements is of itself an enormous obstacle to their use in agriculture. As has been stated already, analysis shows that the water in fresh fæces amounts, on the average, to more than 75%, while in urine there is usually some 95 or 96% of water. So that, even if there were no such thing as water-closets, and if appliances were devised to prevent rain-water and house slops from mixing with night-soil, and for keeping the latter fresh and for transporting it without offence, it would still be true that the proportion of useful ingredients in the mass of water and other useless matters that chiefly constitute night-soil is too small to admit of the general use of this kind of manure.

Until some cheap and easy method shall be discovered of depriving the excrements of their moisture, the use of them must inevitably be restricted to the immediate neighborhood of the spot where they are produced.

Some years ago, an English engineer named Bridges Adams proposed to introduce into London, instead of water-closets, a mechanical arrangement by means of which urine and fæces should be collected apart, so that the urine might be barrelled up and sent by rail into the country. Mr. Adams argued that profit could be derived from such commerce in urine, of which, as he calculated, 24,428 tons could be collected annually in London. But, as was shown at the time by Dugald Campbell, the conception was founded on ignorance. Since, on the average, no more nitrogen could be counted upon in the urine than would be equivalent to 0.7% of ammonia, it would be necessary to use about 30 tons of urine in order to apply ½ cwt. of ammonia to an acre of land. The cost of transporting 30 tons of liquid 20 miles out of London would at that time have amounted to about $10, while half a hundred-weight of ammonia could have been bought for less money than that, either in the form of sulphate of ammonia or of guano, and the cost of applying either of these substances would be vastly less than the cost of applying the urine.

Although the prices of ammonium salts and of guano have increased materially since Mr. Campbell made this computation, his conclusion is still true. It would withal still be difficult to keep the closets clean and odorless, and to prevent the urine from putrefying during the transportation.

Easier to extract Ammonia from Urine than to transport the Latter.

Technically speaking, it could hardly be advisable to try to transport so bulky an article as urine, in view of the fact that the nitrogen in it might be extracted in the form of ammonia, by way of distillation, and the phosphoric acid by methods of precipitation; although, as has already been shown, it may perhaps be true that the urea in fresh urine is really more valuable as plant-food than the ammonia into which the urea changes when urine ferments.

Methods of moving Night-soil.

In regions where large quantities of human excrements are employed in agriculture, as in China and Japan, and indeed in some of the smaller European cities, the materials are collected in jars, or buckets, or barrels, and carried out to the farm land in a tolerably fresh condition. Several convenient arrangements for facilitating such transportation have been devised, such, for example, as small barrels permanently fastened to handbarrows, or a barrel hung between the wheels of a handcart; or tubs are used that are provided with handles or ears, through the slots in which a pole can be thrust, so that two men can readily lift and move the tub even when it contains a considerable weight of material. Such tubs or barrels, when tightly covered, can be moved without offence. They commend themselves in the country in cases where many persons are congregated at any one place, and where there is not enough water at hand for the proper supply of water-closets.

When properly managed, movable tubs or barrels are preferable on several accounts to vaults or cesspools, such as were ordinarily employed before the introduction of water-closets. These vaults were simply sunken cisterns of wood or brickwork, in which the excrements were allowed to collect until there was occasion to empty the vault. Usually they were emptied or partially emptied once a year, or sometimes even less frequently. From being left so long undisturbed, some part of the contents of the cesspool were constantly in a state of putrescence. Offensive gases were continually exhaled from these receptacles, and, even when tightly built at first, they were ultimately liable both to leak and to overflow, and so to poison the neighboring ground and the water of wells which was derived from that ground.

One advantage to be credited to the primitive system of tubs and barrels is, that, unlike cesspools, any leakage or overflow from them would be quickly detected, and easily remedied before the ground in their vicinity had had time to become surcharged with the foul liquid.

Methods of utilizing Night-soil.

Allusion has already been made, under the head of Composts, to the mixing of night-soil with peat and loam, both for the sake of absorbing the liquid and the odoriferous portions of the material, and for exciting the fermentation of humus. Indeed, an ordinary method of dealing with night-soil is either to bring it directly to land that is to be ploughed, or to compost it in the fields with earth, and valuable manure may be had in this way, especially in case the night-soil should happen to be fresh; and particularly in localities where canals permit the material to be cheaply and easily transported.

There was formerly a farm near Paris to which night-soil was brought in bulk in boats, whence it was pumped into pipes that carried it to the fields. It was applied, by way of irrigation, in conjunction with water from the canal, much dilution being needed when night-soil is applied to growing crops.

Peat Poudrette.

In some European cities attempts have been made to prepare merchantable manure from night-soil by mixing with it peat, peat charcoal, charcoal dust, or tan bark, in quantities large enough to solidify the mass. But the products thus prepared have had very little real value, considered as commercial manures. The following table contains the results of analyses of mixtures of peat and night-soil as prepared in various cities of Northern Europe.

	Water.	Organic Matter.	Ash Ingredients.	Nitrogen.	Phosph. Acid.	Potash.
Braunschweig (Schultze)	83.10	14.60	2.30	0.78	0.22	0.28
Munster (Koenig) . .	87.45	10.13	2.42	0.55	0.44	0.17
Bielefeld (Koenig) . .	83.82	10.47	5.61	0.36	0.51	0.40
Groningen (Fleischer), private house . . .	69.85	. . .	. . .	0.84	0.32	0.28
Do., public place . .	86.53	. . .	. . .	0.63	0.25	0.31
Dresden, silica poudrette (Schroder)	26.6	7.3	58.6[1]	0.44	0.35	. . .
	4.0	8.0	79.8[1]	0.46	0.35	. . .

One trouble with these peaty products, and with analogous mixtures, is that much of the nitrogen exhibited by analysis is simply the inert nitrogen that was naturally contained originally in the peat or other diluent.

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[1] Insoluble in acid.

City "Compost."

In several European cities so-called "composts" are prepared by the municipal authorities by mixing the night-soil with all manner of refuse, such as street sweepings, ashes, and other kinds of "dry dirt" collected from houses. Such mixtures must necessarily vary very much in composition in different cities, and in any one city also, according to the different kinds and quantities of materials that are added to the night-soil. Analyses of some of these "composts" are given in the following table.

		Water.	Organic Matter.	Ash Ingred.	Nitrogen.	Phosph. Acid.	Potash.	Lime.	Mag.
Brussels (Petermann)		4.20	22.89	72.98	0.89	0.60	0.31	3.17	0.74
Bremen (Fleischer)	I.	31.05	...	...	0.57	0.44	0.30	2.68	...
	II.	35.51	...	...	0.47	0.55	0.24	2.70	...
	III.	28.52	...	...	0.53	0.58	0.23	2.76	...
Emden (Fleischer)	I.	55.74	...	...	0.43	0.48	0.42	1 77	...
	II.	27.80	...	...	0.79	0.95	0.66	2.62	...
	III.	55.74	...	...	0.49	0.59	0.40	1.60	...
Groningen (Fleischer), mean of the analyses of 4 years		63.18	...	...	0.73	0.50	0.24	1.79	...
Cologne (Dietrich) . .		...	...	...	0.24	0.19	0.18	1.48	...
Brünn (Kohlrausch) . .		40-43	9-15	46-48	0.5-2.0	0.01-0.84	0.60	...	...
Berlin (Heidepriem) . .		...	5.97	...	0.41	1.06	2.33	22.63	1.11

Poudrette.

Formerly, during many years, large quantities of night-soil were manipulated in one of the suburbs of Paris for the purpose of making "poudrette," and the process employed there has a certain historical importance, because the Parisian poudrette became in some sort a standard of comparison to which other analogous products were naturally referred. Some old quarries at Montfaucon, just outside of Paris, had been, by some slight alteration, converted into a series of basins or tanks. Night-soil was poured into the uppermost basin, where a good part of its solid contents sank to the bottom at once, while the liquid portions were made to flow slowly and methodically through a set of the lower basins, which served as receptacles to collect whatever solid matter the liquid held in suspension. The cleared liquid finally escaped through a fine sieve into the Seine.

Whenever a sufficient quantity of sediment had collected in either of these settling tanks, the liquid was run off from that tank, or, if need were, it was pumped over into the next basin, and the deposit was removed from the bottom of the tank to a great field contiguous to the establishment, and there spread out to dry. The layer of mud was harrowed from time to time to facilitate the drying. It need hardly be said that the product obtained in this way had very little chemical value. But, on the other hand, all accounts agree that the stench from the works was wide-reaching and abominable.

Manifestly, the process was radically vicious, and it is well to consider it carefully on that very account. The fact that the making of this poudrette was so long persisted in by the Parisian authorities shows how little was known until very recently of the true theory of manures; while the parallel fact that people could be found willing to pay money for a product so nearly valueless shows how hard beset farmers must have been before the days of guano and commercial fertilizers properly so called. It teaches how greatly favored farmers are nowadays in having an abundant choice of really good and cheap manures.

One good word, however, can be said in favor of poudrettes that were similar in character to the old Parisian product: their mechanical condition was excellent; and this was a very important matter at a time when no other manure shared this quality. A dry, inoffensive powder, that can be sown with seeds from a machine, must commend itself in numerous instances. Another point to be noticed is, that the Parisian poudrette was probably full of germs of the nitric ferment. To this fact may justly be attributed the chief part of the good effects that were obtained when the poudrette was applied to the land; that is to say, it excited the nitrification of the humus of the soil, and was in so far a source of biological, rather than of chemical power. Several analyses of the Parisian (Montfaucon) poudrette have been published, as follows:—

	Water.	Organic Matter.	Total Nitrogen.	Ammonia.	Nitric Acid.	Phosph. Acid.	Lime.
Boussingault and Payen	41.4	. . .	1.56	. . .	. . .	. . .	. . .
Jaquemont	. . .	. . .	1.90	. . .	. . .	. . .	. . .
Soubeiran (1847) . .	28–32	29.00	1.78	0.78	. . .	3.73	. . .
L'Hôte (1848) . . .	30.20	32.81	1.52	0.59	0.30	4.18	6.70

Poudrettes in great variety have been made in many other localities. Generally, they appear to have consisted of the sediment from night-soil (either with or without the addition of small quantities of copperas, gypsum, alum, or the like) dried in the air; though in many cases the sediment seems to have been more or less diluted by the addition of peat, or peat charcoal, sawdust, coal ashes, gypsum, or some other absorbent that had been added to facilitate the drying, and mitigate the stickiness of the material. Of course the product must vary in composition according to the amount of inert matter that has been added to it, as well as according to the state of freshness of the night-soil employed. In the following table, analyses are given of poudrettes that were formerly made at the cities named: —

Poudrettes, made at	Water.	Organic Matter.	Total Nitrogen.	Phosph. Acid.	Potash.	Lime.	Magnesia.
New York City, Lodi Manuf. Co. (reported by S. W. Johnson)	32.52	14.88	0.95	1.06	1.38	1.05	trace
	15.60	18.40	0.98	...	...	...	...
	25 62	14.80	0.95	...	...	...	...
Hartford, Conn. (S. W. Johnson)	39.97	20.57	1.01	0.87	...	...	...
	60.01		1.06	1.05	...	...	...
Dresden, Saxony,							
(Müller)	19.50	20.80	2.10	2.50	1.50	2.70	0.70
(Scheven)	18.42	11.25	1.34	...	...	...	...
(Bretschneider) . .	15.91	35.12	1.68	2.75	0.81	6.28	
Cologne (Grouven) . .	12.80	36.20	2.01	3.01	0.55	...	...
Brünn (Kohlrausch). .	7–16	20–53	1.0–2.5	2.5–3.0	0.8–1.3	...	...
Königsberg (Klein) . .	...	31.00	1.73	1.57	...	...	...
Leipzig (Dietrich) . .	13.40	31.20	2.10	2.96	0.61	1.07	...
Metz (Stutzer)	27.71	25.87	1.48	2.95	0.64	...	...
Av'age comp. of modern German poudrettes (Wolff)	11.5	37.4	1.8	2.8	1.1	...	...

Blood Poudrette.

Sometimes poudrettes have been made by mixing solid excrement, or the solid part of night-soil, with blood from slaughter-houses, and drying the mixture. The product is naturally rich in nitrogen, and was doubtless a powerful manure, though apt to vary considerably in composition, as is shown by the following analyses: —

		Water.	Organic Matter.	Ash.	Nitrogen.	Phosph. Acid.	Potash.
Brünn (Kohlrausch)	1871	9.38	74.10	16.52	9.08	0.87	0.64
	1871	8.73	87.81	3.45	12.44	3.46	...
	1872	7.94	32.44	59.62	2.09	2.60	0.88
Vienna (Kohlrausch)	1873	7.76	42.79	49.45	4.42	...	...

Phosphate Poudrette.

Another class of poudrettes that contained considerable quantities of phosphoric acid were formerly prepared by mixing phosphates with the sludge from night-soil, — notably spent bone-black, which helped to dry the material. Analyses of these phosphatic poudrettes are as follows. In many of these cases the sediment from night-soil had doubtless been mixed with blood as well as with bone-black; or the mixture of blood and bone-black that is obtained in some processes of refining sugar had been added to the night-soil.

Phosphatic Poudrettes made at	Water.	Organic Matters.	Nitrogen.	Phosph. Acid.	Potash.
Berlin (Lucanus)	8.22	48.69	7.14	14.10	...
	8.47	65.36	6.53	8.72	...
	12.26	43.13	3.22	3.73	...
Breslau (Hellriegel)	7.26	60.20	9.30	8.29	...
Hanover (Hellriegel)	20.48	25.23	2.51	15.83	...
	12.12	27.82	3.90	19.11	0.42
	9.04	34.26	2.65	16.98	0.36
Dresden (Fleck)	...	49.85	3.56	14.16	(phosphate of lime)
Berlin (Heidepriem)	5.61	46.73	5.11	11.75	
Vienna (Kohlrausch)	9–19	22–30	1.4–2.3	3.3–10.7	0.8–2.0

In the category of phosphatic poudrettes may be mentioned a product prepared by a secret process by one Thon, which attracted considerable attention among chemists some years ago. Whatever the cost of making the material may have been, its composition was excellent, as was shown by repeated analyses made by several chemists. These analyses showed the following per cent of substances:—

Water	10–12
Organic and volatile matters	30–40
Ash ingredients	50–60
Nitrogen	4–6
Total phosphoric acid	10–12
Potash	1.5

Nearly one half the phosphoric acid, viz. 4½ to 5%, was soluble in water, and the remainder, excepting one or two per cent of ferric and magnesium phosphate, was in the form of precipitated phosphate of lime. One of the analyses indicated that 1¾% of the nitrogen was in the form of ammonia, and that nearly half of one per cent of the nitrogen was in the form of urea. So large an amount of soluble phosphoric acid, taken in connection with the presence of 15% of sulphuric acid in the ashes of the product, went to show that the process of manufacture may perhaps have consisted in adding superphosphate of lime to fresh excrements, perhaps with the addition of a little free sulphuric acid also.

Thon submitted his secret to the chemist Dietrich, who several times prepared small quantities of poudrette in accordance with the formula, and found that every particle of the nitrogen in urine could be preserved by means of it. Thon's poudrette was a dry, yellowish powder.

Ta-feu.

Another product of Chinese invention, known as Ta-feu (Taffoë of the Germans), was originally prepared by kneading excrement and loam together, moulding the product into bricks and drying the latter in the air. A so-called Ta-feu marl, prepared some years since at Königsberg from night-soil, contained 4% of organic matter, ⅓ of a per cent of nitrogen, and ⅓ of a per cent of phosphoric acid.

Processes of Evaporation.

If fresh urine were to be evaporated to complete dryness so carefully that none of its nitrogen should be decomposed, an extremely powerful fertilizer would be obtained; each 100 lb. of which would contain some 25 lb. of nitrogen, 4 lb. of phosphoric acid, and 5 lb. of potash and soda. But to obtain 100 lb. of such residue an amount of urine would have to be taken equal to all that is voided in a day by 1,000 men. (Stoeckhardt.)

According to Nesbit, if fresh human excrements, solid and liquid together, were thoroughly dried, each 100 lb. of the product would contain some 17 lb. of nitrogen and 3 lb. of phosphoric acid, or in a ton there would be say 340 lb. of nitrogen and 60 lb. of phosphoric acid. Even sewage evaporated to dryness may contain, according to one of the English commissions, 30% organic matter, 70% ash ingredients, 6½% nitrogen, 1¾% phosphoric acid, and 1% potash.

Efforts have not been wanting to put the idea into practical form, and in several German towns really good manure seems to have been obtained in this way, i. e. by acidifying with sulphuric acid tolerably fresh excrement that is collected in barrels, and evaporating it to dryness. The first five analyses in the following list are of poudrettes known to have been prepared in this way, and the other specimens appear to have been similarly treated.

Composition of Dried Excrement.

	Water.	Organic and Volatile Matter.	Nitrogen.	Phosph. Acid.	Potash.
Milburn Co. (Voelcker)	10.49	59.69	6.5	5.12 (phosph. lime)	
Stuttgard (Soxhlet) . . .	....	....	7.52–9.96	2.73–3.50	...
Heidelberg " . . .	....	....	8.8–9.1	3.0–3.1	...
Augsburg " . . .	....	....	6.0–6.1	3.0–3.7	...
Munich (Soxhlet) from vaults		....	8.4–9.6	0.7–1.0	...
Berlin (Märcker) . . .	....	....	4.69	4.05 (2.94% soluble)	
" (Fittbogen) . . .	....	....	4.65	4.09 (3.16% soluble)	
" (Ziureck) . . .	....	....	4.65	(2.60% soluble phosph. acid)	
" " . . .	....	....	5.16	3.38	2.26
Münster (König) . . .	....	....	5.59	3.27	2.48
Halle (Märcker) . . .	....	....	5.00	2.91	2.70
Braunschweig (Schulz) .	....	....	5.30	3.10	3.20
" (Fruhling) .	....	....	5.15	2.95	2.89
Hamburg (Ulex) . . .	....	....	5.30	3.39	2.31

Similar poudrettes prepared from tolerably fresh excrements, as obtained by Liernur's pneumatic process, have been found to contain the following percentages, as obtained at

	Water.	Nitrogen.	Phosph. Acid.	Alkalies.
Dortrecht (Burgh) . . .	12.0–22.5	1.6–7.0	1.6–4.0	...
Hague	16.84	7.80	2.0	...
Breda	22.10	6.69	1.1	...
		(4.25% as ammonia)		
Dublin (E. W. Davy) . .	15.86	6.32	6.85 (phosphates)	
Wiesbaden (Fresenius) .	14.82	7.56	2.66	3.10
		(5.7% as ammonia)		

It does not appear as yet whether any legitimate money profit has been gained by making these poudrettes. Indeed, it is doubtful on the face of the matter whether profit can possibly be gained by burning fuel to drive off the large amounts of water with which even fresh excrements are diluted, for the sake of getting the fertilizing constituents. The probabilities are, that the labor expended and coal consumed in making such poudrettes must cost more than the dried excrement is worth. Perhaps the making of them may have depended primarily upon efforts of the municipal authorities to find some outlet for the night-soil.

There was no sense, at all events, in making an English product known as "sulphated urine," which was prepared some years ago by adding to stale urine enough sulphuric acid to neutralize the ammonia, and then evaporating the liquid to dryness. For although the dried sulphated urine was really rich in plant-food, and was an

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efficient manure, it was not worth the cost of manufacture. A similar remark will apply to a process tried much more recently in Germany, by which the liquid portion of night-soil was evaporated in vacuum pans.

A more reasonable plan, putting sanitary considerations aside, was tried at one time, outside of Paris, by an inventor named Chodzko. To clarify and disinfect the liquid night-soil, there was added to it either sulphate of magnesia or a mixture of the magnesium sulphate and sulphate of iron, together with a little tar, and potashes enough to destroy the acid reaction of the mixture. The liquid was then subjected to a process of evaporation which consisted in making it trickle over a large surface of fagots held up in a framework, — as in the well-known process of concentrating weak brines by "graduation," — and finally beating the fagots to detach the incrustations which had formed upon them. In good weather, new portions of the liquid were run in upon the fagots two or three times a day, and after the lapse of a fortnight or three weeks in summer, or of two months in winter, the twigs were sufficiently incrusted to be left to dry out. On analysis, the fertilizer beaten from the fagots showed the following percentage composition: —

Organic Matter.	Water.	Sand and Clay.	Magnesia and Oxide of Iron.	Total Nitrogen.	Ammonia.	Nitrates.	Phosph. Acid.	Lime.
53.53	17.75	4.50	4.50	4.20	0.65	trace	4.48	4.10

The product was distinctly superior to ordinary poudrette, such as was then prepared at Paris.

Baron Podewils proposed, as one method of treating fresh excrements, 1st, to prevent them from putrefying by means of smoke; 2d, to dry the matter down to about half its bulk by artificial heat; then, to mix with it absorbents, such as coal ashes, peat powder, soot, or the like (even finished poudrette would answer); and to mould the plastic mixture into bricks which could be dried in the air. Finally, the dried bricks were crushed to powder. The following analyses, by Wein, relate to such poudrette as this, and to the making of it.

	Excrements dried down without any Addition.	Half-dried Paste.	Half-dried Paste after Addition of Ashes.	Finished Poudrette prepared with Ashes and Soot.
Water	9.01	42.69	38.57	7.65
Organic and volatile matter	59.13	38.58	35.67	68.78
Ash ingredients	31.87	18.73	25.76	23.57
Nitrogen	10.65	7.34	7.04	5.32
Phosphoric acid	4.48	2.54	2.18	3.90

Excluding water in each case, the dry substance contained per cents of

	Excrements.	Half-dried Paste.	Paste and Ashes.	Finished Poudrette.
Organic and volatile matter	64.97	67.31	58.07	74.47
Ash ingredients	35.03	32.69	41.93	25.53
Nitrogen	11.89	12.80	11.45	5.76
Phosphoric acid	4.81	4.43	3.55	4.22

Treatment with Sulphates.

Sulphates of one kind or another, particularly sulphate of iron (copperas), have often been used for treating night-soil. In most European cities it has long been customary to exercise great care in emptying privy vaults, to avoid the offensive gases which are liable to be given off when the contents of these receptacles are disturbed. As a preliminary precaution, a quantity of a solution of the ferrous sulphate, or of some other disinfecting agent, is thrown into the vault, and the muddy liquid is then pumped out into tight wagons by means of force pumps, or it is drawn into great iron cylinders in which a vacuum has been established by the condensation of steam. Care is taken to prevent the escape of offensive gases into the air, — sometimes by compelling the foul air from the pumps to pass through a little stove full of burning charcoal, by which means the odor is destroyed.

Of course, the sulphate of iron, when thus used, arrests a large quantity of ammonia, by converting the carbonate of ammonia into sulphate, though the special merit of the copperas in this case is that it absorbs sulphuretted hydrogen. It is as a disinfecting agent rather than a fixer of ammonia that copperas is here used. It acts also as a germicide, to destroy the microdemes which cause fermentation and putrefaction, and to prevent their growth also. Thus it is, that, when applied to fresh excrements, copperas acts as a preservative, and hinders their decay.

According to Pettenkofer, if fresh excrements were treated immediately with a solution of copperas (1 part in 2 or 3 parts of cold water), less than an ounce of the salt per head and day would be sufficient to prevent the materials from undergoing ammoniacal fermentation. Excluding winter weather, a dozen or fifteen pounds of copperas, obtained at a nominal cost, would suffice for treating the excrements of an individual for a year. It is to be said, however, that, as regards night-soil, the deodorizing powers of copperas are but partial; it arrests sulphuretted hydrogen, it is true, but has no action upon a variety of other offensive matters which are always present.

In view of the fact that ferrous compounds are apt to be injurious to plants, it would be well not to apply night-soil that had been treated with copperas immediately to crops, but to leave it exposed to earth and air long enough for the ferrous compounds to become converted to the ferric condition. As has been said in another connection, sulphate of iron has often been used upon ordinary manure heaps to hinder their decay, and to prevent a real or supposed loss of ammonia; and so have pyritous coal and pyritous lignite, from which sulphate of iron is formed by the action of the air.

Sulphate of zinc, also, and chloride of zinc, have sometimes been used to disinfect night-soil, in much the same way as sulphate of iron.

A fertilizer called "urate" was at one time made in England by adding gypsum to urine, and collecting and drying the precipitate produced. This precipitate contained a considerable proportion of the phosphoric acid of the urine, though very little of its nitrogen; and since the principal value of urine depends upon the nitrogen contained in it, the process was not one of any merit.

Gypsum has often been mixed with night-soil also, to decompose the carbonate of ammonia and hold the ammonia as a sulphate. It is inferior to copperas, however, since it does not destroy the odor of sulphuretted hydrogen, and is far less effective as a germicide than copperas. It has no power to mitigate the peculiar offensive odor of putrid urine, which is due to the presence of some substance quite distinct from ammonia.

Many years ago, sulphate of ammonia was sometimes prepared as a commercial product by filtering fermented urine through gypsum; but the process was offensive and inconvenient, and would be much too costly nowadays, when ammonia is to be had as a waste product at gas works. Indeed, even if the gas liquor were not to be had, it would be cheaper to obtain ammonia from fermented urine by way of distillation, than by means of the old gypsum process.

Manufacture of Ammonium Salts from Urine.

In view of the ready volatility of ammonia, it would be comparatively speaking easy and inexpensive to procure this substance from fermented urine by way of distillation, as is done in the case of the ammoniacal liquor of gas works, if it were only possible to collect large quantities of urine without offence, or even if it were economically practicable to control the fermentation of urine so that it could be brought to the factory in a condition of tolerable freshness. During many years, more or less sulphate of ammonia has actually been manufactured from urine at Paris, and it is possible that it is still so made there; though it is none the less true, that, ever since gas has been manufactured from coal, the amount of sulphate of ammonia prepared from urine has been inconsiderable in comparison with that made from gas liquor.

As has been already shown, when water that contains ammonia is heated, the whole of the ammonia will go off in the first fifth of the water that evaporates. Hence it would only be necessary to distil off one fifth part of the bulk of the fermented urine in order to expel the whole of the ammonia that was contained in it, and which would amount to something like one fifth of one per cent of the original liquid. The distillate might be carried directly into sulphuric acid to form sulphate of ammonia, or it might be led into another batch of urine, which could thus be converted into a more concentrated solution of ammonia, fit perhaps to be mixed directly with the acid.

One idea, suggested by Bolton and Wanklyn, was to lead the ammoniacal fumes arising from the evaporation of urine into a box filled with trays charged with sulphate of lime. By the action of the carbonate of ammonia on the lime sulphate there would be formed carbonate of lime and sulphate of ammonia. But on heating this mixed product, carbonate of ammonia would exhale, and could be collected, while sulphate of lime would again be formed. Another plan was to lead the ammoniacal fumes from the urine into a clear solution of superphosphate of lime. From this liquor, after evaporation, a double phosphate of lime and ammonia could be made to crystallize out.

In distilling stale urine it would be well to add to it a small quantity of milk of lime, or even chalk, in order to decompose any phosphate, sulphate, chloride, or other non-volatile ammonium salt, that might be present. This lime would combine with the phosphoric acid in the urine, and render it insoluble, so that this constituent could be saved as well as the ammonia. It being thus easy to save the only two ingredients of urine that have an appreciable value, there is really no need of thinking of a process so troublesome as that of evaporating urine to dryness as a means of utilizing it.

Urine may be kept Fresh.

Several chemists, notably Alex. Müller and Grouven, experimented many years ago with the view of finding some means of preserving urine so that it might be collected and put to use by the process of distillation just now alluded to. So far as the mere prevention of putrefaction was concerned, they found that urine could be preserved in several ways long enough for the purpose now in question. The presence of almost any free acid, or of an acid salt, in urine, will prevent the action of the ferment which causes urea to change to carbonate of ammonia. Nitric acid is specially powerful, sulphuric acid much less so. Ferrous sulphate and the sulphates of copper and zinc are effective, and so are carbolic acid, and coal tar, and tannin. As is now known, almost any germicide would answer the purpose. In case fresh urine were thus acidified, for example, it would be an easy matter to neutralize the acid at the ammonia works, and to prepare the urine for distillation by mixing with it a quantity of urine that was already undergoing the ammoniacal fermentation, and allowing it to stand for a day or two. It is manifest, however, and the point was freely admitted by Müller, that special appliances would be required for mixing the preservative agent with the fresh urine, and that the tanks and other apparatus used would have to be frequently and carefully cleaned.

In one word, it appears that, beside all the ordinary costs of collection and transportation, a good deal of trouble would have to be taken in order to obtain a supply of urine without offence, and it is precisely this trouble which there is no need of taking so long as ammonia can be obtained for less from the distillation of coal.

Lack of Raw Material.

Grouven, on the occasion of his examination as to the possibility of utilizing the product of the public urinals at Cologne, encountered yet another difficulty, viz. that of obtaining enough of the raw material (fresh urine) to keep a factory in profitable operation. At Cologne he found that 45,000 cwt. of urine could be collected in a year, which was at the rate of 40 lb. for each inhabitant, or nearly 10% of all the urine voided by the population of the city. Supposing the whole of this urine were evaporated, it would be possible to get 4%, i. e. 1,800 cwt. of dry residue, and if the manufacturer were to double this quantity by adding to it acids, or superphosphate, there would still be no more than 3,600 cwt. of matter to be sold, — a quantity so small that a factory could hardly be maintained upon the profits from it. He estimated that at least 10 times the given quantity of urine would be needed, under the conditions of which he wrote, in order that a profitable business could be based upon it.

When considerations such as these come in to increase the inherent difficulties of the subject, — viz. those that depend on the offensive odor and small value of the original materials, and their rapid deterioration by fermentation, — it is no wonder that manufacturers of manures are no longer much encouraged to grapple with the problem of utilizing night-soil; let alone the fact that the conviction gains ground almost everywhere that the best way of dealing with the filth of cities is to dilute it enormously with water, and throw away the dirty water as speedily as may be possible.

Magnesium Processes.

Long since it was a favorite idea among chemists that both ammonia and phosphoric acid might be precipitated from fermented urine by means of a magnesium salt. One suggestion was, even, that a magnesium salt might be mixed with fresh urine which should then be made to ferment. In either event, the insoluble double phosphate of ammonia and magnesia, so familiar to analytical chemists, was to be thrown down as a precipitate which could be collected and used as a manure. The fertilizing power of this precipitate is undoubted, since it has been proved by numerous experiments.

There are several difficulties which prevent the practical application of this idea. The double phosphate is a crystalline precipitate, which, when formed in presence of much water, separates out very slowly. So much time is required in order that it may be deposited from a liquid so dilute as urine is, that a very large number of tanks would be needed at a factory in order that the contents of any one of them could be left at rest long enough to insure complete deposition of the precipitate. Moreover, the presence not only of a soluble magnesium salt, but of an excess of some base, such as hydrate of magnesia or hydrate of lime, is necessary to insure the complete precipitation of the ammonia.

Several French inventors have sought to insure the precipitation of all the ammonia by adding phosphate of magnesia to stale urine, or night-soil, or sewage, and it would be easy to prepare any quantity of this compound at small cost from superphosphate of lime and waste chloride of magnesium, which is procurable at Stassfurt. Sometimes it has been suggested that phosphate of soda and a magnesium salt might be mixed with the urine or night-soil, or a mixture of superphosphate of lime and a magnesium salt. One proposition looking to the more rapid separation of the double phosphate was to filter the fermented urine through a bed of peat charged with sulphate of magnesia. One trouble is, that the double phosphate is not so completely insoluble in saline solutions as it is in pure water or in water charged with ammonia.

Use of Alum and Sulphate of Alumina.

Though rather inefficient disinfecting agents, the sulphates of alumina have sometimes been employed in the preparation of poudrette from night-soil. Probably the process of Forbes and Price, described under the head of sewage on a subsequent page, would be better for this purpose than sulphate of alumina.

Admixing of Excrement with Lime.

The use of lime for preserving fresh excrements has repeatedly attracted attention, and many futile efforts have been made to prepare merchantable fertilizers by means of it.

Mosselmann, in France, proposed the following process. Quicklime is slaked with half its weight, or with an equal bulk of urine, and the dry powder thus obtained is mixed with solid excrement in the proportion of 2 parts excrement to 2½ parts of the slaked lime. The mixture is ready for transportation the moment it is prepared, and it contains all the ingredients of the original urine and solid excrement, excepting a quantity of water which was evaporated by the heat disengaged in the act of slaking. The amount of water thus lost is about equal to the weight of the lime. With the water some small traces of ammonia escape that existed ready formed in the matter treated.

Of course a large quantity of ammonia would be expelled by the lime if the latter were added to old night-soil that had undergone fermentation. In order to obtain the best results, the process imperatively requires that the excrement and the urine shall be treated while still fresh.

It was claimed at one time that the dry product could be kept indefinitely without undergoing change, but it appeared subsequently that a certain amount of change does slowly occur. The process has been modified somewhat to meet the case where a large quantity of urine is to be treated; for when urine alone is mixed with lime, the latter can be made to absorb, by repeated additions, as much as three times its own volume of the liquid, while something more than half of the water of the urine escapes in the form of steam.

In operations carried out upon the large scale, it was found that even in winter one part of lime could be made to absorb three parts (by bulk) of mixed solid and liquid excrement. But in summer somewhat more water went off in the process of slaking, so that the final product contained only 20% of lime. The process has evidently a certain degree of merit, and it is easy to admit that cases may occasionally arise, as at prisons, barracks, or factories (gas works?), where it might be employed with advantage in the interests of agriculture. From the large amount of lime required, however, it would be very difficult to put the process in practice as a sanitary measure, looking to the economical purification of cities. The difficulties attending the handling and marketing of large masses of material would be practically insuperable. One of the sewage commissions of the city of Berlin computed that, if the process were applied to a city of 550,000 inhabitants, nearly a million and a half bushels of quicklime would be needed every year.

Practical experience at the farm has still to determine whether there may not be some localities, as in regions of heavy clay lands, for example, where limited amounts of the limed excrement would be valuable enough as manure to permit the material to be transported to moderate distances.

Analyses of the product as obtained (I.) from Mosselmann himself, and (II.) as prepared in two different German towns, indicated the presence in it of the following per cents of

	I.	II.	
Water	34.00	46.00	30.00
Organic and volatile matters	18.38	10.00	9.00
Nitrogen	0.69	Not determined.	
Phosphoric acid	0.19	1.06	1.23
Lime	24.40	30.30	41.00
Magnesia	0.63	0.77	0.28
Potash	0.28	0.04	

Hervé-Mangon reports, as the result of numerous analyses, that Mosselmann's product hardly contains half of one per cent of nitrogen.

About the same time that Mosselmann published his process in France, the chemist Alex. Müller was occupied with experiments upon the action of lime, at Stockholm. Müller found that, when fresh fæces are mixed with lime, only an insignificant quantity of ammonia is given off. He proved, indeed, by numerous experiments, that fresh fæces do not contain, on the average, more than 0.1% of ammonia.

Müller, like Mosselmann, found that it is easy to convert solid excrement into a dry powder, fit to be transported, by the use of lime. He urges, however, that the proportion of lime should be kept as small as possible, and that it will usually be best to resort to air and the sun's heat in order to complete the drying. He suggests also, that, whenever the process is applied to night-soil that has begun to ferment, some acid substance such as superphosphate of lime, or peat wet with sulphuric acid, should be employed to retain the ammonia.

A German mechanic named Schur, seeking to bring Müller's ideas into practical use, constructed a closet in such manner that, while the fæces and urine were separated, the fæces were covered with a small quantity of powdered lime mixed with a little fine charcoal, something in the same way that dry earth is now applied in the earth-closet. A sample of the dry product from one of these lime-closets was found to contain 2% of nitrogen and 4% of phosphates.

The mode of action of the lime upon the excrement is similar to its action upon other forms of nitrogenized organic matter, as has been set forth under the head of Fish Waste. Insoluble compounds of lime and organic matter are formed, which, so long as they are kept dry, resist decay and putrefaction. A small incidental advantage is that the lime retains the phosphoric acid of the urine also, though the amount of it is never very large (according to Müller the proportion of phosphoric acid in fresh urine may vary from 0.1% to 0.3%). For that matter, Müller found that the phosphoric acid in fresh urine may be completely precipitated by adding a small quantity of a soluble lime salt and a little hydrate of lime, i. e. enough to make the liquid alkaline.

The evaporation of water from the excrements by the heat developed during the slaking of the lime is an important consideration, of course, but it is altogether subordinate to the union of the lime and the organic matter on which the preservation of the material depends.

It is noteworthy that the use of lime for preserving excrement is a very old idea, and that, in addition to the efforts above mentioned, numerous attempts have been made to put it in practice.

Sir Humphry Davy, in his Lectures delivered in London at the beginning of this century, says: "The disagreeable smell of night-soil may be destroyed by mixing it with quicklime. If exposed to the atmosphere in thin layers, strewed over with quicklime, in fine weather, it speedily dries, is easily pulverized, and in this state may be used in the same manner as rape-cake, and delivered into the furrow with the seed."

From a subsequent paragraph it is to be inferred that Davy believed that the Chinese use quicklime in this way; and it is well known that quicklime is often placed in coffins in China to prevent or retard the decomposition of the corpse. As long ago as 1802, Estienne proposed to prepare manure from night-soil by mixing its solid portion with lime, and drying the mixture in the sun. Payen at one time had much to say upon the subject.

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CHAPTER VI.

A GLANCE AT THE HISTORY OF THE USE OF MANURES.

It would appear that the use of ashes, as obtained by burning trees or grass upon the land to be cultivated, was the first kind of manuring employed in most cases, if not in all cases. Then the dung of animals was used, then straw, and so on.

Dung was obtained at first from wild vegetation, notably that from bog-meadows, pastures, and forests; afterwards it was derived from water-meadows, and, still later, from proper hay-fields; then from fallow crops and from the refuse of merchantable crops, viz. from straw, bran, brewers' grains, potato slop, grain slop, oil cake, beet cake, rice feed, gluten meal, and the like.

The use of straw as an addition to stable manure also characterizes one very important stage in the history of agriculture, — a stage which it is always interesting and profitable to consider. In new countries that are fairly fertile, straw is often regarded as a mere nuisance and incumbrance to the farmer, which he is glad to get rid of as speedily as may be, by burning it, or by throwing it into a river if opportunity offer. Many parts of California are in such condition to-day that the straw of the grain crops is burnt at once, either as fuel for heating the boilers of threshing-machines, or merely for the sake of destroying it. One great incentive to the burning of straw, especially in a dry climate, is the need of putting it out of the way of taking fire at an unsuitable time, and so doing damage to houses, or fences, or crops.

The extreme dryness of the climate of California makes the problem of dealing justly there with straw an extremely difficult one. During the larger part of the year there is not rain enough to keep the heaps of straw moist, and no way is known of rotting the straw except by bringing water to it artificially, or by making the heaps in some natural depression or miry place. But in climates like that of Central Europe and of our own Northern States, there is little or no trouble in rotting straw if the farmer wishes to do so.

As a matter of history, it would seem that at a very early period straw was used for feeding and bedding cattle in rather a crude way. One plan, often carried out even now with bog-meadow hay by Irishmen in the vicinity of Boston, was to stack the straw near the homestead, and allow the animals to have free access to the stack, so that they could pick out what they wished, and lie upon the portions which had been pulled out and trampled upon, but not eaten. One gain in this system is, that the droppings of the animals tend to collect in one place, instead of being scattered about the field. Stack feeding is really a crude device for saving manure.

Straw-yards.

The straw-yards of old English farms, and of many English farms of the present day for that matter, were little more than methodical expressions of the idea of the stack. These straw-yards were special enclosures, in which cattle were turned loose to eat straw, and to trample upon that which they did not care to eat.

According to Loudon, the straw-yard was often an enclosure at the centre of the farmyard and adjacent to the dung-pit or basin. It had sheds open to the south, and was protected by high fences from north, east, and west winds, — the idea being to let the cattle work at their leisure upon the straw, to allow them to eat more or less of it according to the quality of the straw and the vigor of their appetites, and to trample a large proportion of it, in any event, into the dung beneath their feet.

In Germany, which is in general a much poorer country than England, more attention has always been paid to the methodical feeding out of straw than in England; though even in Germany a large proportion of straw is used for bedding animals that are kept confined in stables throughout the year, and so goes directly to the dung-heap.

It appears to have been found out at a very early period, in a purely empirical way, that the farms which were dressed with manure that contained plenty of straw were kept in better heart than farms which were dressed with mere dung; that is to say, than farms which were dressed with the dung of animals that had not had access to straw, as was just now described, and had not been bedded with straw.

Undoubtedly the acquisition and formulation of this knowledge was a very slow process, but when once the conception had been fairly grasped it was not forgotten. Indeed, there are to-day few rules in agriculture which are so firmly fixed and so tenaciously held as this, viz. that straw must on no account be sold off a farm, but must either be eaten upon the farm by cattle, or be in some way incorporated with their dung and rotted in conjunction with the dung.

Straw unduly esteemed.

In many parts of Europe the owners of land have insisted, since a very early period, that no straw shall ever go off the land under any circumstances. In signing his lease, before taking possession of a farm, the tenant is bound to consume the straw of all grain crops upon the farm, and to apply it to the land in some form; just as he is bound to use upon the farm all the manure which the animals kept upon it may produce. Upon this fundamental basis modern agriculture has been built up.

It is now known very well why it is that straw serves so good a purpose. It is known that straw retains a great mass of potash, lime, and other ash ingredients, which are left behind in the straw after having served their respective functions in the grain plant and helped to perfect the seed.

By carrying back the straw to the land, the farmer is enabled to use these ash ingredients over and over again, and to escape all risk of exhausting the land of inorganic matter, except in respect to the single item of phosphoric acid, which is carried off in considerable quantity by the grain.

Substitutes for Straw.

When once the whole system of European agriculture had come to be based upon the use of straw, this substance was not unnaturally regarded as in some sort a necessity, without which farming could hardly, as people deemed, be carried on with profit. Hence a search for substitutes for straw, and the use of leaves and the rakings of woodland.

The use of leaves as a manure marks in its turn one distinct step in the history of fertilizers. It is, in fact, the point which our immediate fathers had reached here in New England, and it would perhaps be hard to find to-day a good farmer, who has lived his sixty years, who will not insist that it is good practice to collect leaves in the autumn for bedding and composting. One of the most prominent agriculturists in Germany, Professor Walz, who was for a long while Director of the Agricultural School at Hohenheim, the leading agricultural school in the world, insisted strenuously to the last that wood-raking was a very important point in the practice of good husbandry. In the second edition of his little book entitled "Dünger und Waldstreu," issued so recently as 1870, that is to say, in the face of all that was then known of the use of artificial fertilizers, Walz still clings to the old idea with great pertinacity.

For his original text, Walz discourses as follows. The complaints of farmers as to the lack of materials for littering their animals, and the consequent deficiency of manure, grow louder and louder, and are heard in many different regions; while, upon the other hand, the foresters in many districts complain that the rate of growth of wood is continually decreasing because of the too frequent raking of the woodland on the part of the farmers. Meanwhile, he goes on to say, an idea is abroad that Germany has very nearly reached the limit of her power of agricultural production, that she cannot support a larger population than now exists, and that consequently the government should encourage emigration. He then proceeds to tell how these real or imaginary evils may be met and overcome, if the farmers will but avail themselves of the means which are already at their disposal. His book is, in fact, an admirable exposition of the idea which has so often found expression in our own agricultural literature, of using thoroughly the means which are to be found at the farmer's door, i. e. the things which are known to him, and which are readily accessible.

In this way he sought to compose the standing dispute between the farmers and the foresters, and insisted that a part of the plan of conducting a tract of woodland should be to make it produce a crop of rakings for the farmer's use, as well as merchantable timber and cord-wood. Among other things, Walz urges, as has been said, that one capital way of saving dung is to put it upon the field in the freshest possible condition. For he had found in his own experience that fresh dung goes a great deal further, i. e. it expends to much better advantage, than old well-rotted dung.

Dead Leaves contain but little Plant-food.

With regard to the composition of leaves, it should be said, that there is really no very large amount of fertilizing matter in autumn leaves any way, and that they are generally inferior to straw. Considered merely as manure, it will not be worth the farmer's while to spend much time or money in collecting dead leaves.

Of course, leaves are often useful and really valuable to the householder in northern climates as a means of banking up around sheds and barns and houses, to keep out the winter's cold; and in the same sense the leaves may sometimes be valuable for bedding cattle or swine which would otherwise not be sufficiently protected from the cold; and in either of these events the subsequent use of the leaves as manure will follow as a matter of course. But as a general rule, at least for countries that are kept free from fires, the dictum of the German foresters that woods should never be raked is clearly correct.

As a means of promoting the growth of wood, the leaves have a real value which can be realized at no cost whatsoever other than the pang which some farmers would feel of letting the leaves alone.

But in case the leaves are regarded primarily as manure to be used upon farm-land, the cost of collecting and handling them will seem large, and the expense would in fact usually amount to more than the leaves are worth. Autumn leaves are necessarily comparatively poor in potash, phosphoric acid, and nitrogen, since these constituents pass out from the leaves into the body of the tree with the approach of winter, there to be held in store for next year's use. In one sense it would be perfectly correct to say that dead autumn leaves, even those that have never been leached by rain, have been wellnigh exhausted of their most valuable fertilizing constituents. But, as is well known, considerable quantities of the less valuable kinds of ash ingredients, notably silicic acid and lime, remain in the fallen leaves. For the best quality of autumn leaves recently fallen from hard-wood trees, and not yet subjected to leaching or decay, there may be allowed from $\frac{1}{10}$ to $\frac{5}{10}$ of one per cent of potash, from

$\frac{6}{100}$ to $\frac{3}{10}$ of phosphoric acid, and about $\frac{3}{4}$ of a per cent of nitrogen; or in a ton of autumn leaves of the best quality, say 6 lb. of potash, less than 3 lb. of phosphoric acid, and 10 or 15 lb. of nitrogen; whereas in a ton of ordinary straw there would be from 10 to 20 lb. of potash, from 4 to 6 lb. of phosphoric acid, and some 6 or 7 lb. of nitrogen.

The use in the barnyard of peat, and of sods or loam taken from headlands, like the use of leaves, is evidently an outgrowth from the use of straw. This practice of using earth commends itself in general, in spite of the facts that the earth contains but little fertilizing material, and that in getting out the loam or peat a great deal of labor has to be expended for the sake of a very small acquisition in direct chemical power. For it is to be noticed that no other crop is robbed when loam is brought to the barnyard from waste places, and that labor can usually be expended upon this enterprise at times when there is little else to be done upon the farm. Moreover, the task is a more manageable one than that of collecting and storing leaves, and admits of being methodized.

Lime, Marl, and Soot succeed Ashes.

After straw, the use of lime and marl, and of soot, came in, in a purely empirical way; and it is from the use of these amendments, as well as from that of ashes, that the modern practices of using artificial fertilizers have grown up.

First came bones and crushed bones, bone-meal, and bone-black; then guano from Peru and from Ichaboe, bone superphosphate, phosphatic guano and superphosphates made therefrom and from coprolites, sulphate of ammonia, nitrate of soda, Norwegian fish scrap, superphosphates from rock phosphates, rectified guano, American fish scrap, and flesh-meal; and between whiles, rape-cake and other forms of oil-cake, malt sprouts, and rags, as well as the system of feeding animals upon grain and oil-cake, and distillery slop, for the sake of improving their dung; last of all, dried slaughter-house refuse, potash salts, and attempts to gain profit by means of sewage irrigation.

A Survival of Soot Manuring.

An interesting instance of the use of soot in conjunction with straw has recently been noticed on one of the Scotch islands. On the island of Lewis, namely, the huts of the inhabitants are purposely built without chimneys, and have a roof composed of sticks upon which is laid a mass of grain stubble, which in its turn is covered with a thatching of long straw. The prime object of this thick covering is to keep out the cold; but, in the absence of chimneys, the stubble becomes perfectly saturated with soot, and every spring it is taken off and utilized as manure upon the potato-fields.

During the summer the roofs are covered only with the thin outer layer of thatch which is reserved for this purpose; that is to say, the straw is carefully taken off and replaced upon the sticks after the sooty stubble has been removed. But next autumn, when the grain is pulled, the stubble ends of it are put upon the roof. Evidently a tolerably complete manure must be got from the ash ingredients of the straw plus the nitrogen of the soot.

How to use Artificials.

At the present time, one important lesson to be learned is how to use the artificial fertilizers to the best possible advantage in conjunction with dung; or, rather, how to supplement and eke out the dung of animals by means of artificial fertilizers in such wise that the utmost profit shall be got both from the dung and from the chemicals. There are special cases of course where it may be best, on the whole, to use artificial fertilizers by themselves, as upon fields that are distant from the farmyard, and in places that are steep or inaccessible, for in such situations fertilizers that are concentrated and portable may have an enormous advantage over barnyard manure, in respect to economy of carriage and application.

The significance of artificial fertilizers considered as supplements to farmyard manure may be seen very clearly by considering the pains that used to be taken, in districts where high farming prevailed, to "prepare the land" for wheat and for barley. As will be seen more in detail under the head of Rotation of Crops, farmers were averse to applying barnyard manure to these grain crops because of its tendency to encourage too rank a growth of straw. When they did apply manure to these crops, they took care that it should be well rotted. The common plan was to apply the manure to a root crop, or to clover, that preceded the grain. But by means of light dressings of dung used in conjunction with artificial fertilizers, each one upon the crop that is best suited by it, it is possible not only to manure grain directly, but to expend the manure of the farm to better advantage than was the case formerly.

Hereafter, no doubt, the problem how to get along with artificial fertilizers by themselves, without using any dung at all, will present itself in certain localities more commonly than it has hitherto, and this question will be a difficult one to answer in a thoroughly satisfactory and economical way. To solve a problem such as this, there will be needed two or three generations of farmers well grounded in scientific conceptions, and open-minded enough to weigh a prejudice and count it at something like its true worth.

Money Value of Dung.

At present the question is continually asked, How much is a ton of farmyard manure really worth, as compared with a ton of mixed artificial fertilizers? But, as farms are now constituted, it is not easy to give to this question a precise answer, especially in view of the peculiarities of stable manure, which were discussed on a previous page.

Probably, for the generality of cases, the best way of estimating the price of manure will be to observe carefully the cost of making it at each particular farm; or, if the running expenses of his stable are already familiar, the farmer can calculate the cost of buying new quantities of food wherewith to keep more cattle, and estimate what will be the cost of the fertilizing constituents thus obtained. With the definite standard of value thus obtained, the prices of the commercial fertilizers may readily be contrasted.

Considered as a whole, manure can undoubtedly be made at the farm in most localities much more cheaply than a mixture of its constituents could be compounded from purchased materials. But, as has been shown already, whenever occasion requires that a special manure (whether nitrogenous, phosphatic, or potassic) shall be used on a particular crop, it will ordinarily be cheaper to buy and use such special fertilizer as a reinforcement, than to apply enough farmyard manure to supply the needed material. The conclusion being that, almost always, artificial fertilizers should be used in conjunction with moderate doses of farmyard manure to supplement its deficiencies.

According to Voelcker's analysis of farmyard manure three months rotted, there is contained in a ton of it 24 lb. of potash, 6 lb. of phosphoric acid, and 15 lb. of nitrogen, and if 5 cents a pound be allowed for the potash and phosphoric acid, and no more than 10 cents a pound for the nitrogen, the ton of manure will be worth at least $3.00, and a cord (taken as weighing 3½ tons) would be worth $10.50. If 15 cents be allowed for the pound of nitrogen in rotted stable manure, then the ton would be worth $3.75, and 3½ tons $13. But the cost of making and distributing manure on most farms is notoriously less than either of these figures. Perhaps half the sum last named would be a liberal estimate.

Each farmer must, of course, consider for himself, as a secondary question, the cost of hauling and distributing the heavy and bulky manure, and of working it into the land, as compared with the expense of transporting and handling the concentrated fertilizers.

Dettweiler has computed, in the following terms, the cost of producing cow manure per head and per year, at four different farms in Germany, from which the milk is sold as such.

	I.	II.	III.	IV.
Cost of fodder consumed	$138	$136	$153	$149
Cost of care and attendance	11	11	11	11
Cost of bedding, i. e. 1½ tons of straw per year and head	8	8	8	8
Depreciation of the animal, etc.	8	8	12	8
Sum of these expenses	$165	$163	$184	$176
Income from sale of milk	154	149	179	148
Cost of manure of one cow for one year	$11	$14	$5	$28

He reckons that, bedding included, one cow will produce 14 tons of manure in a year.

Proposals for Mixtures.

After all that has been said in relation to the superiority of dung and urine, it is still true — making due allowance for this superiority — that some useful suggestions, both for using the artificial fertilizers in conjunction with farmyard manure, and for using the artificial fertilizers by themselves as substitutes for farmyard manure, or in competition with it, may be got by writing out schemes such as the examples given in the following table, in which the fertilizers or mixtures enumerated contain the stated number of pounds of plant-food.

	Nitrogen.	Phosph. Acid.	Potash.
8 cords of excellent farmyard manure, 3 months rotted, that weighs 3½ tons to the cord	120	168	192
4 cords of such manure and 350 lb. of a superphosphate of 12% P_2O_5 (a mixture used for turnips)	60	126	96
4 cords of the farmyard manure and 400 lb. fish scrap (of 7% N and 6½% P_2O_5)	88	110	96
4 cords of the farmyard manure and 200 lb. Peru guano (of 8% N, 14% P_2O_5, and 3% K_2O)	76	112	102
2 cords of such manure and 1,000 lb. cotton-seed meal (of 7% N, 2¾% P_2O_5, and 1½% K_2O)	100	70	63

	Nitrogen.	Phosph. Acid.	Potash.
A mixture of 500 lb. bone-meal (of 4% N and 23% P_2O_5) and 30 bushels wood ashes @ 48 lb. (of 2% P_2O_5 and 8½% K_2O)	20	154	122
A mixture of 30 bushels wood ashes and 1,000 lb. fish scrap	70	94	122
A mixture of 30 bushels wood ashes and 300 lb. nitrate of soda	46	29	122
A mixture of 30 bushels wood ashes and 1,000 lb. cotton-seed meal	70	57	137
A mixture of 1,000 lb. fish scrap, and 200 lb. muriate of potash of 80%	70	65	100
A mixture of 800 lb. cotton-seed meal, 400 lb. bone-meal, and 200 lb. muriate of potash	72	114	112
A mixture of 600 lb. bone-meal, 100 lb. muriate of potash, and 200 lb. nitrate of soda	55	138	50
A mixture of 1,000 lb. fish scrap and 800 lb. kainit of 12% K_2O	70	65	96
A mixture of 200 lb. superphosphate of 12% soluble P_2O_5, 1,000 lb. fish scrap, and 200 lb. muriate of potash	70	89	100
A mixture of 300 lb. superphosphate of 12%, 1,000 lb. cotton-seed meal, and 100 lb. muriate of potash .	70	64	65
A mixture of 400 lb. superphosphate of 12%, 300 lb. nitrate of soda, and 800 lb. kainit of 12% K_2O .	46	48	96
A mixture (suggested by some of those used by Lawes and Gilbert) of 200 lb. bone-ash (of 32% P_2O_5) that has been treated with acid, 300 lb. sulphate of ammonia, and 500 lb. kainit . . .	60	64	60
A mixture of 500 lb. superphosphate of 12% soluble phosphoric acid and 25 bushels wood ashes	...	84	102

It should be distinctly understood, however, that such schemes can do no more than indicate the amounts of the more important kinds of plant-foods that are contained in the mixtures enumerated. They do not teach that one or another of the mixtures is as good as farmyard manure. Information such as that can only be gained by trial of the mixtures upon the particular field which it is proposed to cultivate.

It will be remembered withal, that the artificial fertilizers are often applied with reference to but a single crop, while it is commonly expected that the influence of a dressing of farmyard manure shall be felt for several years; and it will be well to consider whether an appreciable proportion of the benefit derived from the manure may not be due to the encouragement it gives for the growth of useful microscopic organisms in the soil, that is to say, to its bringing the land into a good condition of fermentation.

In drawing up any such schemes as the foregoing, the farmer will naturally lean towards the fertilizers most readily procurable in his vicinity, and to the kinds of plant-food best suited to the crops he means to cultivate.

Practical Suggestions for Mixtures.

Another way of formulating the quantities of fertilizers to be given to a crop is suggested by the following "general rule," proposed by Heiden as applicable for manuring potatoes either on heavy or on light land. For each pound of nitrogen applied to the land, from 3 to 5 lb. of phosphoric acid should be given, according as more or less time has elapsed since the land was dressed with dung. The amount of nitrogen to be applied to an acre may range from 12 to 25 lb., and that of phosphoric acid from 65 to 75 lb. In case potash is needed, he recommends that 800 or 1,000 lb. of the double sulphate of potash and magnesia should be used.

Some years ago Mr. Lawes, judging from observation and from the field experiments of Gilbert and himself, published some practical suggestions for farmers as to the amounts of fertilizers that can be used with advantage. For wheat he recommended that farmyard manure should be applied directly, in case the land was light; but on heavy land he would have the manure applied to mangolds, and, as a manuring for the wheat that followed these roots, he would strew and harrow in, just before seeding, from 200 to 300 lb. of guano to the acre. Many English farmers, he says, have found their advantage in adding to the guano twice its weight of common salt.

For barley or oats, in case either of these crops should follow grain, he recommended 200 lb. of guano or of nitrate of soda, and 200 lb. of superphosphate, to be harrowed in as before; but in case the crops followed turnips or mangolds, half these quantities of the artificial fertilizers would be sufficient, because of the unexpended manure already in the land.

In case any grain crop should seem to be in need of a top-dressing in late spring, nitrate of soda, applied at the rate of 100 to 125 lb. to the acre, may be commended.

Mangolds are well suited by heavy dressings of farmyard manure, especially when the land is heavy, the manure to be applied at the rate of from 15 to 20 tons to the acre, together with 200 or 300 lb. of guano mixed with 400 to 600 lb. of common salt [or, better, with Stassfurt muriate (?)].

For potatoes, Lawes did not commend the usual method of dressing heavily with dung, but recommended that the dung should be applied to a previous crop, and that the potatoes should receive in their turn 150 to 200 lb. of guano, together with as much superphosphate.

Hops, he says, need to be dressed abundantly with animal or vegetable matters that are not too forcing, such, for example, as woollen rags, wool dust, horn-meal, rape cake, or hide scraps; and it is only in conjunction with such things that the concentrated fertilizers, particularly guano, have given satisfactory results in respect to this crop.

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CHAPTER VII.

POTASSIC MANURES.

It will be observed that the subjects of the preceding chapters — notably Dungs, Composts, and Organic Matters — have been treated of primarily as nitrogenous manures. There remain to be considered several mineral substances which are employed as fertilizers, and among them the compounds of potash may fairly be considered as most important.

As has been seen already, potassium is absolutely necessary for the growth of plants. Indeed, there must be a tolerably large supply of the compounds of this element within reach in order that the plant may prosper. Even the plants that grow in or near sea-water contain a comparatively large proportion of potash.

There is naturally a good deal of potash in the soil, as follows necessarily from the familiar fact of its occurrence in the ashes of plants. Most of this potash comes from the decomposition of feldspar, that is to say, of orthoclase or potash-feldspar, but some of it comes from the decomposition of mica and other minerals. Nearly all clays contain some potash, and even limestones are not wholly free from it. One reason why clay soils are strong, in the sense that they exhibit enduring fertility, is that they usually contain much potash. In several rocky and barren regions in northern and eastern New England, it is noticeable that the occasional farms are usually situated upon slopes or ridges of glacial clay.

Amount of Potash in Rocks and Minerals.

Some of the volcanic rocks are rich in potash. A variety of rock called palagonite, found upon the sides of Ætna and Hecla, contains so much potash, and decomposes so readily, that it has sometimes been used as a manure. But for the recent discovery of better sources of potash, this rock might perhaps have been profitably transported to considerable distances for fertilizing purposes. The proportion of potash (K_2O) in various common minerals may be set down roughly as follows: feldspar (orthoclase), 12 to 17%; mica, 3 to 5%; basalt, 0.75 to 3%; clay slate, 1 to 4%; clay and good loam, 1.5 to 4%.

The nature of the change which may occur during the disintegration of feldspar is well shown by some analyses of Crasso.

	Original Feldspar.	Decomposed Feldspar.	Matters removed.
Silica	65.21	32.50	32.71
Alumina	18.13	18.13	. . .
Potash	16.66	2.80	13.86

In ordinary soils the potash appears to be held for the most part in combination with silica and alumina (or iron oxide) and lime, as has been already stated when speaking of the fixing power of the double silicates of lime and alumina.

Why the Ocean contains Sodium rather than Potassium Compounds.

The importance of the existence of these complex silicates cannot be too strongly insisted upon. Were it not for their restraining power, the potash in the soil would soon be washed out and carried into the sea; for, excepting the silicates, all the ordinary potash salts are readily soluble in water. It is precisely because soda is less readily retained than potash is by the double silicates in the soil, that the sea is salt with chloride of sodium, and not with chloride of potassium. Chloride of sodium is dissolved out from the soil and carried away to the sea by the ground-water more readily than any other saline substance.

It was observed long ago by the mineralogists, that, where silicates of potash and of soda exist side by side in the same mineral mass, and suffer decomposition together, the soda compound often loses its alkali faster than the potash compound. Thus, Struve found in a phonolite (a feldspathic rock), —

	Potash.	Soda.
In natural condition	3.45	9.70
In decomposed condition	5.44	3.26

In a basalt: —

	Potash.	Soda.
In natural condition	1.35	7.35
In decomposed condition	2.62	2.31

It is to be noticed that the double silicate of lime and alumina which holds the potash, and from which plants may draw their supply of this article of food, is usually found only in the finely divided earth or loam which constitutes the soil properly so called, and that at the best the natural supply of potash is small unless the soil contains a good deal of decomposing feldspar, or something such. Hence, whenever crops are taken from the land, the store of potash will after a while be exhausted if no steps be taken to renew the supply. In fact, from the economic point of view, potash is the most important ingredient of manures after nitrogen and phosphoric acid.

Much Potash is returned to the Land.

Practically, a great deal of potash is returned to the land upon most farms, in the form of stable manure, in the refuse from crops, and in composts of one kind or another prepared from vegetable matter.

It is not with potash as it is with phosphoric acid. Potash does not accumulate to such an overwhelming extent in seeds and fruits as phosphoric acid, nor in the animal body either. Hence, in general, in all well cultivated districts a much larger proportion of the potash that has been taken from the land is returned in the form of manure than is the case with phosphoric acid; and in consequence of this fact, considerable difference of opinion has existed as to the utility of buying potash compounds for manure.

The truth of the matter seems to be, that in well tilled, highly cultivated regions, where the land is dunged heavily, and especially where the rocks from which the soil has been produced are feldspathic, there is not apt to be any marked deficiency of potash in the soil.

Soils that respond to Potassic Manures.

But upon the other hand, in countries where the land gets but little manure, and particularly in localities where the rocks are of such character that they can supply only a comparatively small proportion of potash by their disintegration, as is the case in the immediate vicinity of Boston, the benefits derivable from an application of potash to the soil are great and immediate.

Almost anywhere upon the drier, lighter portions of the gravelly "drift" soils of New England, a dressing of potassic manure, especially carbonate of potash, such as occurs in wood ashes, will justify itself at once. There was a striking illustration of this fact in experiments made some years since at the Bussey Institution, and published in the first volume of its Bulletin.

Somewhat similar remarks have often been made with regard to the soil of special localities in Europe. The moorland of North Germany in particular is grateful for potassic manure. But, as a rule, potash seems to be comparatively little needed upon the rich farming lands of the Old World; although every little while some one reports that even there potassic fertilizers have served an excellent purpose, especially on light soils, and with crops that stand in special need of this constituent. Thus, in a recent description of certain farm-land in Scotland, not far from Edinburgh, it is laid down as proved that "clover-sickness," as manifested in that locality, is caused by a lack of potash. At all events, those farmers of that region who have applied Stassfurt potash salts to land that was formerly clover-sick, now raise splendid crops of clover. And they notice that their clover is no longer thrown out in the winter months, as was apt to be the case before potash was used; doubtless, because the plants now get a better developed system of roots before the frosts set in.

So too where sugar beets are cultivated for sale, or chicory roots to be used as a substitute for coffee, or potatoes, or tobacco, large quantities of potash are carried off the land, and the economy of employing special potassic fertilizers to make good the loss has often been strikingly manifested.

Instances of Income and Outgo of Potash.

Heiden has given the following statement in illustration of this matter. Every hundred-weight of sugar beets taken from a field carries away on the average 0.359 lb. of potash; but since a Morgen (= 0.631 acre) of land yields from 140 to 200 cwt. of the beets, it thereby loses from 50 to 72 lb. of potash, no account being taken of the potash in the beet leaves which are left upon the land. Hence, wherever beets are grown year after year for sale, as is not uncommonly done in some parts of Central Europe, there will manifestly soon be need of dressing the land with some kind of a potash compound.

Karmrodt has given the following computation of the yearly outgo and income of potash on an estate of 1,717 Morgen, that had neither water-meadow nor pasture to support its cattle, and which had for years been devoted to the growing of sugar beets.

Yearly export of potash: —	
In the crops	103,812 lb.
In products from cattle	473 "
Total export of potash	104,285 "
Amount of potash added to the land: —	
In form of guano and night-soil	8,439 "
In the seeds planted	1,021 "
In the dung of cattle, —	
As obtained from food grown on the estate	74,875 "
As obtained from hay and oil-cake bought	4,967 "
Total potash added to the soil	87,302 "

Hence the excess of potash removed each year was equal to 16,983 lb., or as much as would be contained in 14,615 cwt. of hay. It appears from this statement, as well as from the calculation of income and outgo of potash that was given under the head of Farmyard Manure, that there is little risk of exhausting any land of potash so long as the land is adequately manured with the dung of cattle that are supported on hay from water-meadows (or bog-meadows or salt marshes), and on straw and clover.

Several calculations as to the income and outgo of potash on farms thus conducted have been given by Heiden in his "Düngerlehre." His figures show emphatically, that, far from losing potash, many European farms continually become richer and richer in this constituent. In consequence of this tendency, no money profit can be expected from the application of special potassic manures, considered merely as sources of this particular form of plant-food, upon farms that have long been kept in good heart by means of abundant dressings of farmyard manure. But wherever forage crops, or even straw, are sold off a farm in undue proportion, or where large quantities of beets, carrots, cabbages, turnips, onions, potatoes, or tobacco are sold year after year, the judicious use of potash salts may be expected to more than repay the cost of them.

In cases where milk is sold off a farm, it commonly happens that more or less fodder (corn-meal, shorts, cotton-seed meal, or the like) is bought to reinforce the hay on which the animals are fed, and that in this way more potash is brought to the farm than goes off in the milk, not to speak of the rough fodder, or of the potash in that fodder, which in New England comes to the arable part of many farms from browse, wild pastures, and bog-meadows.

Before the discovery of the mine of potash compounds at Stassfurt in Germany, about the middle of this century, it was a very difficult matter for those farmers who had no access to wood ashes to procure special potassic fertilizers to meet the wants of particular crops, such as those just now mentioned, and the wholesale cultivation of them was consequently less easy than it is now.

Potashes obtained from various Plants.

A glance at the proportion of potash obtainable from various plants in the manufacture of potashes upon the large scale, will show at once that some plants, or rather some parts of plants, contain much more of it than others. One thousand pounds of old spruce wood yield ½ lb. of potashes; of old poplar wood, ¾ lb.; of old oak wood, 1½ lb.; of corn stalks, 17½ lb.; of bean stalks or sunflower stalks, 20 lb.; of grape-vine twigs, 40 lb.

As a rule, potash pushes forward into the extremities of plants, i. e. into the twigs and new leaves. It will be noticed how well worth saving for the compost heap the grape-vine clippings must be, and the remark is as true of the shoots and twigs of almost any other bush or tree. It has long been familiarly known that grape-vine twigs are thus rich in potash, and it is a fact of daily observation in wine countries, that considerable quantities of bitartrate of potash are obtained from the argol, or tartar, which is deposited in the wine casks after the grape-juice has fermented. Hence a popular impression arose, and still persists, to the effect that grape-vines are specially liable to exhaust the soil of potash. This notion is untrue. It was disproved by Boussingault as long ago as 1850; for, having analyzed all the products that are carried away from a vineyard, and compared the amounts of potash in these products with the amounts of this substance carried off the land in other crops, he found that the grape-vine could not be regarded as a plant standing in special need of potash.

He states that, in the locality in question (Alsatia), there is carried off from a hectare (= 2½ acres) of land by a crop of

	Alkalies. Kilos.	Phosph. Acid. Kilos.
Potatoes	63	14
Beet roots	90	12
Wheat, with its straw	27	19
Wine, including clippings from the vines, and the marc or residuum left in the wine-press	17	7¼

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It is to be observed, that figures like those just now given, which have been made in the interest of the potash-boiler, do not necessarily give the true agricultural value of the ashes of the several plants enumerated. For example, the ashes from any plant rich in silica, like the various grasses and grain-bearing plants, would contain much silicate of potash which is not readily soluble in water. Such ashes would yield only a comparatively small amount of potashes when treated with water in the leaching-tubs, although they are really very valuable as a fertilizer.

In some parts of Europe, straw and weeds were formerly burned for the manufacture of potashes, and the idea was several times thrown out that it might be well in those districts to favor the growth of plants specially rich in potash. Hermbstädt long ago tried the plan of planting wormwood, which grows upon very poor soil, for the production of potashes. He found, by experiment, that one Magdeburg acre (18,000 square feet) would yield three crops a year, or some 20,000 lb. of dry plant, 2,000 lb. or more of ashes, and 900 lb. of potashes; or 12% of ash, and about 5% of potashes. Beichos proposed to grow tansy for the same purpose, and stated that an acre of this plant will yield 1,250 lb. of potashes. Fresenius proposed the common marigold of Europe (Chrysanthemum segetum) as a potash-producing plant. It grows wild in enormous quantities in certain districts, and the ash contains about 25% of potash.

Stems and Stalks of Tobacco.

Tobacco stems, from which the leaves have been stripped, are known to have considerable fertilizing power, and are consequently often returned to the land. Professor Johnson reports that the anhydrous stalks of tobacco plants contain nearly 5% of potash, $\frac{7}{10}$ of a per cent of phosphoric acid, and nearly $3\frac{1}{3}\%$ of nitrogen, of which $\frac{2}{10}$ of a per cent is in the form of nitrates. At the time when the leaves are stripped from them, the stalks are thought to contain usually some 46% of water. Hence, when in that condition, 100 lb. of the stalks would contain 2.6 lb. of potash, 0.36 lb. of phosphoric acid, and 1.85 lb. of nitrogen. From 1,500 to 2,000 lb. of the dry stalks, containing $15 to $20 worth of fertilizers, may be yielded by an acre of land.

Tobacco stems also, i. e. the midribs of the leaves as rejected by manufacturers of cigars, have considerable repute as a fertilizer. Johnson reports, in one sample that was purchased in New York city, 33% of water, 5¼% of potash, ½ a per cent of phosphoric acid, and nearly 2% of nitrogen. In another sample, believed to be somewhat damaged, he reports 46.7% water, 6¼% potash, $\frac{4}{10}$% phosphoric acid, and 1.6% of nitrogen. In a specimen of fine tobacco dust, sifted from tobacco clippings, he reports 9.6% water, 2.8% potash, 0.5% phosphoric acid, and 2.4% nitrogen. The sample of stalks examined, and the dust also, contained a considerable amount of chlorides, say ½% of chlorine, while the stems, from totally different fields, contained a much smaller proportion. Lime was present in the samples in considerable quantity.

Dietrich's analyses of midribs from the Palatinate gave an average of 22% ashes, 15% moisture, 8% potash, 2% phosphoric acid, and 2% nitrogen, of which last almost a quarter was in the form of a nitrate.

Barilla from Strand Plants.

Until near the beginning of the present century, large quantities of fused ashes of peculiar character, called barilla, which contained much carbonate of soda as well as some carbonate of potash, were prepared by burning certain strand plants, notably those of the genus Salsola (saltwort). Much barilla was sent into commerce from Sicily and from the east coast of Spain, where the plants that produce it were regularly cultivated, mown, and dried like hay, and then burned in pits. In the vicinity of Carthagena, for example, where the ordinary rotation of crops was wheat, barley, and fallow, the barilla plants were often sown on the fallow field. So, too, in case the wheat crop failed from want of rain, the wheat-land also was sown for a crop of barilla.

This old practice is not a little interesting, in that it goes to show that farmers in saline districts formerly possessed one means of improving their land and hindering the ill effects of over irrigation, which has ceased to be useful since soda ash is made more cheaply from common salt than it can possibly be got from plants. Goebel found in ashes obtained by burning saltwort plants, from the vicinity of the Caspian Sea, 5% of potash that was soluble in water, and 30% of soda.

Kinds of Potassic Manures.

Potash is employed as a manure in the form of wood ashes; the ashes of cotton-seed hulls; the greensand of New Jersey; the slurry of the glass-makers, which is an impure sulphate of potash, obtained as a waste product in the purification of pearlash; as sulphate of potash and chloride of potassium; and as "potashes," which in this country is usually a mixture of hydrate of potash and carbonate of potash.

Mayer's analyses of New York potashes gave, in per cent, —

	"Best."	First Quality.	Second Quality.	Third Quality.
Carbonate of potash (K_2CO_3) . . .	44 to 25	56	15 to 53	38
Hydrate of potash (KHO)	50 to 44	6	39 to 5	. .

American potashes are prepared by placing wood ashes in tubs above a layer of caustic lime, leaching with water, evaporating the lye to dryness, and igniting the residue.

Wood Ashes as a Manure.

Most farmers in New England are agreed as to the high value of wood ashes, considered as a manure. So firm is their faith in this regard that many persons have drawn from it the false inference that potash is not only the chief thing, but the sole thing, needful to fertilize the land and to bring up those sections of the country which have been run out by careless cropping. But it is not fair to class wood ashes as an exclusively potassic manure. Beside potash, wood ashes contain one or two per cent of phosphoric acid, and various other ingredients which are of value to plants; notably a little magnesia and a great deal of carbonate of lime. The importance of these incidental constituents is made plain by the esteem in which leached ashes are held by our farmers, although from the leached ashes all but a very small proportion of the original potash has been washed out.

Leached ashes consist for the most part of carbonate of lime. Ordinarily they contain no more than from ⅓ to ½ of one per cent of real potash, and but little more than one per cent of phosphoric acid. Some kinds of peat ashes contain potash enough to be worth considering, but they are rare.

The ashes of coal contain a trace of potash, but not much, if any, more than ordinary loam or than many kinds of sand. Whatever merit pure coal ashes may really possess must depend upon their mechanical condition, which fits them to do good on clay soils and on soils rich in humus, such as those of reclaimed bogs.

A favorite way of applying wood ashes is as a top-dressing to grass-land and to pastures, where, by encouraging the growth of clover and some of the better kinds of grasses, they do good service in crowding out inferior kinds of grasses, and in destroying weeds and moss.

Wood ashes are esteemed also for potatoes and corn and roots, and they are used in the preparation of composts, as has been said, and there is room probably for their greatly extended use in this particular way.

The Crops best suited by Potash.

In Germany, where the use of potash salts as manure has lately been largely extended, they are particularly commended for beets, potatoes, clover, cabbages, and hops, — all leafy plants, it will be noticed. But it is upon clover especially, and other leguminous plants, that potassic manures show the most remarkable effects. The old notion of farmers, that by applying wood ashes to grass-land they can " bring in " clover, is a case in point, which consists perfectly well with the results of methodical experiments. Messrs. Lawes and Gilbert, in experiments with a variety of different plants, continued through long terms of years, found the potassic manures more useful with clover, beans, and peas than with any other crops. Dr. Gilbert has recently summed up this experience in the following terms. It is found, he says, that easily assimilable nitrogenous manures have generally a very striking effect in increasing the growth of grain crops, such as wheat, barley, and oats; although these grain crops contain comparatively little nitrogen, and take but little of it from the land. The leguminous crops, on the other hand, such as peas, beans, clover, and others, although highly nitrogenized, are by no means characteristically benefited by the use of direct nitrogenous manures, such as ammonia salts and nitrates, though nitrates act much more favorably than ammonia salts. It appears, indeed, that we may say, Use phosphates for turnips and such like roots, potash for leguminous plants, and active nitrogen for grain.

Price of Wood Ashes.

Until a comparatively recent period, wood ashes were really almost the only commercial fertilizer that was procurable in this country, and the price of 12½ cents per bushel, at which they were formerly bought and sold, had come to be a sort of standard of value which withstood many vicissitudes. But, for the region around Boston at least, there came a time when ashes were hardly to be had at any price. From 1850 to 1870, for example, they could hardly be looked upon in the light of a commercial manure in this vicinity. Even leached ashes were at that time sold at 25 cents the bushel on the seaboard, and fresh ashes were not to be had.

Latterly, thanks to the great diminution in price of all kinds of potash compounds which has resulted from the development of the potash industry at Stassfurt, wood ashes begin to be brought in by rail from the less settled part of the country, notably from Canada, and they can be ordered from Oswego or Montreal by the car-load nowadays at tolerably reasonable rates.

It may be said in passing, that the price of 25 cents the bushel for leached ashes, as just now given, was much higher than such ashes are really worth. Fresh ashes, on the contrary, are often worth more than 25 cents per bushel, as has been set forth in some detail in one of the numbers of the Bulletin of the Bussey Institution.

Of course the value of ashes may vary considerably according to their source, though practically this variation is less than would be supposed at first sight. Ashes are richer or poorer in potash and other useful ingredients according to the kinds of plants from which they have been derived and to the soil upon which the plants grew. And particularly according to the parts of the plant that have been burned. The ashes of twigs (fagots for example) would always be worth much more for agricultural purposes than the ashes of heart-wood taken from the middle of an old tree; and, in general, the smaller and younger the wood burned, the better would be the ashes. Practically most fires are fed with cord-wood that has been cut under very much the same conditions of growth almost everywhere. So that the variations in the composition of the ashes from house fires are, comparatively speaking, small. To judge from the books, taking what is known of the composition of the ashes from young twigs and that from heart-wood, one would say that the proportion of potash in ashes might vary from 5 to 20%. But a much better criterion of the real composition of ashes is afforded by the experience of potash-makers in this country, according to which a bushel of "house ashes" weighs about 48 lb. on the average, and yields rather more than 4 lb. of potashes.

I have myself investigated this question somewhat in detail, and have found by the analysis of a number of samples of house ashes that selected samples contain 8½% of real potash and 2% of phosphoric acid; or say 4¼ pounds of potash and 1 pound of phosphoric acid per bushel. Hence there is enough potash and phosphoric acid to make the bushel of ashes worth 20 or 25 cents, and, beside that, some 10 or 15 cents additional may be allowed for the "alkali power" of the ashes, i. e. the force of alkalinity which enables the ashes to rot weeds and to ferment peat. The notion that the ashes from soft woods, such as pine and poplar, are worthless, is an error. The soft woods yield comparatively little ashes, and the ashes are so light that they may readily be blown away by the wind; but weight for weight, the ashes from soft woods appear to be as good for agricultural purposes, or very nearly as good, as those from hard woods.

Alkaline Lyes make Soils cohere.

One peculiarity which ashes owe to their alkaline quality is worthy of special attention, since it must often exert a very decided influence upon the capillary power of the soils to which the ashes are applied. It is a well-established fact, that alkaline lyes, that is to say, either the caustic alkalies, or solutions of the alkaline carbonates, viz. carbonate of potash, such as is got by leaching wood ashes, and carbonate of soda also, make clay and loam more plastic and adhesive than simple water can. Both carbonate of potash and carbonate of soda tend to keep clay in a "puddled" or "tamped" condition, as the terms are. A ball of moist clay or loam thus charged with an alkaline carbonate does not tend to crumble or fall to powder during the process of drying; but remains a hard lump. A tenacious, fire-proof cement for stopping holes in stoves and stovepipes is made by mixing powdery clay with fine wood ashes and working the mixture with water to a smooth paste, which is applied as such, and becomes hard on drying.

It is because of this peculiarity of the alkalies that it often becomes impracticable to till soils when any large proportion of carbonate of soda is contained in them; that is to say, such "alkali soils" cannot be tilled economically by the ordinary mechanical appliances of the farm. No matter how often such a soil is ploughed or harrowed, it will always remain a mere mass of hard clods, unless, indeed, it is muddy. Such a soil cannot be brought to a condition of good tilth by mere ploughing, unless the alkali be washed out of it by drainage and irrigation, or unless it is neutralized, as Hilgard has suggested, by means of gypsum: —

$$Na_2O,CO_2 + CaO,SO_3 = CaO,CO_2 + Na_2O,SO_3.$$

Unless the alkali be removed or decomposed, such soils cannot be made mellow, simply because the alkali causes the particles of earth to stick together. The earth can be torn asunder into lumps (clods) by the ploughshare, but the furrows will not fall down to powder on drying, which is the essential feature of good tillage.

These alkali soils have given much trouble in California in recent years. But it may well be asked whether in many cases the difficulty does not arise from the presence of too much of a good thing. It seems plain, on the face of the matter, that the tilth of many a porous open soil might be improved if its particles could only be held together a little more tightly than they are held naturally, so that the capillary water may be lifted more freely and retained more forcibly. It was for the sake of securing this result that the Norfolk County farmers laid such stress on having their light soils trampled down firmly by means of cattle and sheep that were fed upon the land, and that the Scotch long since resorted to the use of heavy rollers upon their light lands.

I have in fact found, by experiment upon light land, that this very advantage was obtained by the application of wood ashes to the soil. A plot of land dressed during several years with what any farmer would have considered a large quantity of wood ashes became so firmly bound that a yoke of heavy oxen had some difficulty in dragging a plough through the soil in dry summer weather. The furrow where it crossed this plot was a mere mass of clods. Yet through all the years of the experiments that plot had manifestly been better supplied with water from below than any of the adjacent plots.

Action of Potashes on Soil-nitrogen.

An objection is sometimes made to wood ashes, as a manure for tobacco, that the plants grow coarse, probably because of nitrogen supplied to the crop by the action of potash on humus; such action, namely, as was discussed under Alkali Composts. This power of potashes to make the nitrogen of the soil available for plants is strikingly shown in clearing wooded countries. For wherever a heap of logs is burned, it is noticed that vegetation is apt to be particularly rank and luxuriant precisely where the largest quantities of ashes are lying. Several writers have expressed surprise that these appearances should be as they are, for their first thought was that so large an amount of ashes must destroy vegetation. It is noticed that wheat or other grain sown upon the newly burned land often "lodges" at those spots where heaps of logs have been consumed. This rankness of growth is doubtless to be attributed first to a superabundant supply of nitrogenous food, though, from what was just now said, there can be no doubt that the spots charged with alkali are in many cases better supplied with moisture by capillary lifting than the remainder of the field.

It was noticed long ago by Lorain, that the ground where the log heaps were burned seemed to be moister than the surrounding soil. All this consists, moreover, with what Professor Hilgard has noticed upon the alkali soils of California, where the alkali "puddles" the clay in the soil, and prevents water from draining away from it. As Hilgard says, "Soils impregnated with alkaline carbonates may generally be recognized by their extreme compactness and refractoriness under tillage, and by the fact that they are apt to form 'low spots' in the general surface of non-alkaline land, i. e. places where turbid clay water, dark with dissolved humus, will lie for weeks after the higher land appears dry."

Ashes of Cotton-seed Hulls.

There is a variety of ashes procurable in commerce that has been derived from the hulls of cotton-seeds, as obtained in the process of "decortication," which precedes the grinding and pressing by means of which oil is extracted from the seeds. The hulls are commonly used as fuel at the oil factories in conjunction with wood or coal, whence it happens that the ashes vary considerably in composition. They are naturally more or less valuable according as they contain less or more of the ash of the supplementary fuel. According to Johnson, those which are lightest in color are usually richest in potash.

As brought to the North, cotton-hull ashes commonly contain from 18 to 30% of potash, chiefly soluble in water, and free from any contamination with chlorides; and from 5 to 10% of phosphoric acid, of which from 1½ to 2% is soluble in water. It appears, therefore, that, considered as a fertilizer, cotton-hull ashes are much more concentrated than ordinary wood ashes. Although the supply is limited, the price at which cotton-hull ashes have been sold hitherto ($35 to $40 the ton in New England) is so low that they have been by far the cheapest source of potash in the market. They have been used with advantage for manuring tobacco, and are specially prized by tobacco growers.

Lime-kiln Ashes.

There is yet another product, called lime-kiln ashes, which can be procured by the car-load from Vermont and other localities where lime-kilns are fired with wood. But these ashes consist chiefly of lime-dust. They usually contain less than 2% of potash, and less than 1% of phosphoric acid. They may be regarded as wood-ashes admixed and diluted with from 4 to 6 times their weight of lime, much of which has become partially air-slaked.

One special objection to the contaminating lime is, that part of it has been "over-burned," and so left in hard lumps, which do not readily fall to powder on being wet. I have heard the objection from a man who farms a rich bottom land in the western part of Massachusetts, that "there are hard lumps of lime in such ashes which will take the edge off a hoe quicker than thought." Of course where the lime-kilns are fired in part with coal, the ashes from them would be still poorer in potash and phosphoric acid.

Brick-kiln Ashes.

In a sample of ashes from a brick-kiln that had been fired with chestnut wood, Prof. Johnson reports 1½% of potash, and less than 1% of phosphoric acid. The sample consisted chiefly of brick-dust and sand. Such ashes as these could be used with advantage on many soils in the immediate vicinity of the kiln; but they are not worth enough to be carried to a distance. So, too, in respect to the lime-kiln ashes, there are doubtless special cases and places where they might be employed with profit by intelligent farmers, although they are not to be compared with wood ashes, and have no such general applicability as the latter.

Greensand.

The greensand, or so-called "greensand marl," of New Jersey has hitherto been considered as of only local importance, though it contains a good deal of potash, and has been used with great advantage in the regions where it is found. According to Professor Cook, of New Brunswick, N. J., the potash may be taken on the average as 5% of the whole weight of the sand; and since a bushel of this substance weighs about 80 lb., it would contain 4 lb. of potash, or about as much as is contained in a bushel of good wood ashes. The greensand moreover often contains as much as 1 or 2% of phosphoric acid, though, as a matter of course, both these constituents are in a very different condition from those found in ashes.

Considered as a manure, the greensand acts rather slowly. It is said, for instance, that its effects will be perceived upon land for ten or twelve years. It is bulky, moreover, and, so far as its contents of potash and phosphoric acid are concerned, would not repay the cost of transportation to any very great distance.

Greensand analogous to the fixing Silicates.

Most writers who have discussed the subject hitherto have been disposed to make the objection that the greensand is a sand merely, and neither a manure proper, nor a soil, nor a disintegrated mineral, such as would contain food immediately available for the plant. But, in point of fact, the greensand is a hydrated silicate of iron and potash. It belongs to the mineral species glauconite, and is probably — one might almost say doubtless — competent to act as an agent for absorbing lime, soda, ammonia, and the like, from the soil-water, and at the same time yielding up its potash for the use of plants. If this view be correct, the greensand deserves to receive far closer attention than has been accorded to it hitherto.

Before potassic fertilizers were as abundant as they are now, it might have been questioned whether it would not perhaps be well in some localities to prepare artificially a hydrated silicate of potash and alumina to be applied to light hungry soils in order to provide a permanent store of potash from which plant-food should be given up slowly through the action of saline matters in the soil-water. But in the green-sand the desired double silicate is found ready made. The rock palagonite, previously mentioned, is another natural product whose action upon certain soils would be well worth studying as a scientific experiment.

State of the Potash in Soils.

It is to be remarked, that most of the potash immediately available for crops that is contained in ordinary soil probably occurs there either in the form of hydrated double silicates or in that of double humates, though in really good soils, or in those recently manured, some small portions of soluble potash salts may be found clinging to the earth by mere adhesion. A part of the "fixed" potash is doubtless dissolved by mere water, and brought to the plant as an aqueous solution, and some of it is probably dissolved out by carbonic-acid water, and so carried to the plant in the form of potassium bicarbonate, while still another portion may be dissolved out directly from the soil by the action of acids exuded by plant roots. Each of these agents would naturally dissolve some potash from mere gravel, or from crumbled or broken rocks, but it is to be supposed that their solvent action is of paramount importance when exerted upon the hydrated silicates and the humates.

Potash from Rocks.

It has often been proposed formerly to obtain potash for agricultural purposes by decomposing feldspar and other potassic rocks artificially by means of chemical agents. Professor Wurtz, of New York, for example, proposed long ago to decompose the New Jersey greensand by fusing it with chloride of calcium; and several persons have thought to obtain soluble potash by fusing or fritting feldspar with lime. Neither of these methods has ever had any economic importance, and since the discovery of a mine of soluble potash compounds at Stassfurt they are likely to be forgotten. No doubt, however, there are many potassic rocks, such as the greensand, and the palagonite, and various traps and zeolites, possibly some kinds of feldspar even, or slates, which in some instances might repay the cost of reducing them to powder. Small batteries of stamps driven by water power, such as were formerly used abroad for pulverizing bones in inland agricultural districts, might perhaps be established with profit in certain localities. The experiment is well worth trying, in some localities where greensand can be procured, whether the cost of reducing the sand to fine powder would not be more than repaid by the increased efficiency of the product as a manure.

The Potash Mine at Stassfurt..

The deposit of potash minerals at Stassfurt, already repeatedly referred to, is one of so much importance that a brief description of it will be in order. The products from this mine will doubtless henceforth control the price of potash compounds everywhere. The deposit in question occurs in connection with a bed of rock salt of enormous extent, above which, capping it as it were, repose layers of several saline minerals, notably compounds of potassium, magnesium, and lime.

There seems to have been an inland lake or sea, through the evaporation, or rather the boiling down, of the waters of which rock salt was deposited by crystallization until the mother liquors above the salt became so highly charged with compounds of potassium, magnesium, and calcium, that crystals of these compounds were deposited in their turn on top of the salt.

As long ago as 1839, borings were made at the locality in the hope of finding salt, and brine was actually obtained in 1843; but it was so highly charged with magnesium compounds that it was not worth working. After a while, certain geologists who had studied the locality expressed the opinion that the magnesia must have come from some other source than the bed of rock salt of whose existence they were convinced, and this view was corroborated by the matter brought up by a new boring, made in 1848 or 1849. It having thus been proved that the magnesia must have come from a bed lying above the pure rock salt, mining operations were undertaken in 1851 in order to get at the salt. By 1856 two shafts had been sunk to the depth of some 1,100 feet, where a bed of impure rock salt was struck. This was some distance below the potash mineral, the value of which was then unsuspected.

Pure rock salt was reached in 1857, as had been anticipated, and its extraction was proceeded with; but it was not until 1859 that the true value of the layer of potash mineral was recognized. The dip of the layers and general character of the deposit having by this time been well made out, a new pit was sunk nearly a mile from the first, by means of which both the potash and the salt can be reached at a less depth and worked to better advantage than before. This new shaft was finished in 1862, and since that time enormous quantities of the potash minerals have been extracted both at the old and the new mine.

The bed of salt beneath the potash minerals is of unknown depth; but, taking the salt in connection with its covering, the entire deposit may be conveniently divided into four principal layers, or beds, each of which is well characterized at the centre by the predominance of minerals peculiar to it, though at the points where the layer touches the layers above and below it the character of its contents is by no means so well defined. The rock salt at the bottom is wellnigh pure, though interspersed with veins of anhydrous sulphate of lime. Next above is a 100-foot thick bed of salt, interspersed with veins of a complex sulphate of potash, soda, and magnesia (polyhallite). Above this is a 90-foot bed of sulphate of magnesia (kieserite), mixed with a double chloride of potassium and magnesium. And, finally, at the top is a 70-foot bed of the potash mineral proper (carnallite); this is a hydrated double chloride of potassium and magnesium, containing, when pure, about 27% of dry chloride of potassium. The mineral is detached in large masses from the bed by means of gunpowder. The cost of extracting it is exceedingly low, and the amount produced is limited only by the demand.

In the beginning, the crude potash mineral was sent into commerce to be sold as a fertilizer under the name Abraum Salt, and it is still used in that way to a certain extent; but chemical works were soon established for the purpose of purifying the mineral, and the secondary products of these works are now used as manures.

Muriates of Potash.

A great variety of commercial fertilizers are now prepared at Stassfurt, and sold at cheap rates. Both chloride of potassium and sulphate of potash may be had in varying degrees of purity. One of the varieties of the chloride in particular, known as "muriate of potash of 80%," has been largely used, and may perhaps be as good as any other of the Stassfurt products for the generality of purposes. It may be said to contain just half its weight of real potash (K_2O). There is another variety of the muriate stronger than the foregoing, classed as "95 to 98% muriate," but it probably has no special advantage for agricultural purposes.

Muriate of potash, no matter what its strength, may answer well enough for clover, grass, corn, and ordinary root crops, and it has the merit of being cheaper than the sulphate. But it is objectionable in respect to sugar beets, tobacco, and sometimes as regards potatoes. The chlorine in it hinders beet sugar from crystallizing, and, in some soils, tends to make potatoes waxy rather than mealy. It impairs the quality of tobacco leaves to such an extent that they command a lower price than would have been the case if another kind of potash salt had been used. Hence sulphate of potash that contains no contamination of chlorides is greatly preferred for tobacco and beets; and is esteemed to be best, on the whole, for potatoes also.

Sulphates of Potash.

Until quite recently, it has not been easy to procure sulphate of potash of the requisite purity, except by buying the pure pharmaceutical preparation at a rather high price. It is true that so-called sulphates of potash from Stassfurt have for some years been readily procurable from the dealers in fertilizers, and that some of these products have even been called "high-grade sulphate of potash"; but they were usually so heavily admixed with chlorides that they could not possibly be commended for those crops to which chlorides should not be applied.

The commonest of the Stassfurt products that contain sulphates is the so-called "kainit," which is prepared by calcining one of the natural minerals. It usually contains about 12% of real potash, but is a mere mixture of chlorides and sulphates of potassium, sodium, and magnesium. There is usually enough chlorine in kainit to amount to rather more than one quarter of its weight.

Another product sold as sulphate of potash generally contains as much as 37 or 38% of real potash, and is in so far better than kainit; but it contains much chlorine also, even to the extent of more than one third its weight. More than two thirds of the potash in this compound must be in the form of muriate of potash, and less than one third of the potash in the form of sulphate. Both these mixtures are so impure that it is incorrect to speak of them as sulphate of potash. Subsequently a stronger sulphate, comparatively speaking free from chlorides, was occasionally brought to this country. It contained 80% or more of pure sulphate of potash, which would be equal to 43% of real potash. Quite recently an article, advertised as "96 to 98% sulphate of potash," has been brought to us from Stassfurt.

Another compound of potash, sulphuric acid, and magnesia, known as double sulphate of magnesia and potash, appears to be worthy of consideration, because it could probably be readily and cheaply prepared quite free from chlorides. When dry, this compound should contain some 38% of sulphate of magnesia, and from 54 to 56% of sulphate of potash, which would amount to about 30% of real potash. An analysis by Alex. Müller showed 26%.

In addition to the foregoing "sulphates," there is another product of American manufacture, which was thrown upon the market in large quantities several years ago, that needs to be carefully guarded against. In view of the lower cost of freighting the muriate than the sulphate, it was suggested some years since that, at American chemical works, muriatic acid should be made, not from common salt, as was then customary, but from Stassfurt muriate of potash, so that there should be obtained incidentally high-grade sulphate of potash for use in agriculture. This idea was acted upon, but with a very vicious modification.

In making muriatic acid, the manufacturer is obliged to employ an excess of oil of vitriol in order to obtain a fusible residue which can be run out of the retorts without trouble. Hence, instead of working upon the basis expressed by the equation

$$2\,KCl + H_2O,SO_3 = K_2O,SO_3 + 2\,HCl,$$

there is taken more sulphuric acid, somewhat as in the following equation, so as to get an "acid sulphate of potash":

$$2\,KCl + 2\,(H_2O,SO_3) = (K_2O,H_2O,2\,SO_3) + 2\,HCl.$$

Ordinarily, about 1½ molecules of sulphuric acid are taken for two molecules of chloride of potassium, and a "sesquisulphate of potash" is obtained, and this product should be roasted to expel the excess of acid, and obtain real sulphate of potash. In the case now cited, the dealers in fertilizers omitted to have the roasting process attended to, and they threw upon the market considerable quantities of an acid corrosive product unfit to be applied directly to land that was to be seeded or planted. This acid sulphate of potash would doubtless be excellent for killing weeds, insects, and worms upon land infested with these pests, or for composting with weeds to kill their seeds. It would be of interest, for example, to test its efficacy upon patches of grass-land where the long-enduring white grub of the June beetle has established itself. But the farmer needs to know precisely what the material is, and to use it with care. It was wholly inexcusable to sell it as "sulphate of potash."

I have been told of instances where serious money loss resulted from using this acid salt. On transplanting young tobacco plants, for example, into land that had been dressed with the acid sulphate, the growth of the plants was checked, and the crop practically spoiled. Similar trouble occurred also on using "formula fertilizers" which had been compounded with the acid sulphate. Analogous instances have been cited in the Report of the Connecticut Experimental Station for 1877, page 42.

In case such material should fall into a farmer's hands, the acidity might be corrected by means of ashes, either leached or fresh, or by means of bone-black in case the mixture could be left to itself for some time before spreading it. Doubtless sulphate of potash, pure enough for agricultural use, will eventually be prepared in this country in the manner above described.

Cheaper to transport Muriate than Sulphate.

It is noteworthy that the cost of freight for the potash in the muriate of 80%, which contains half its weight (i. e. 50%) of real potash, would be only about one quarter as much as would have to be expended on the crude sulphate of 20% real potash, for the molecular weights of the sulphate and the chloride differ considerably. Thus,

$$\begin{array}{lll} K_2 = 62 & \qquad & K = 31 \\ S = 32 & & Cl = \underline{35.5} \\ O_4 = \underline{64} & & 66.5 \\ 158 & & \end{array}$$

But, having regard to potassium in each case,

$$\frac{62}{158} = \text{say } \frac{6}{16} \text{ or } \frac{3}{8}; \text{ while } \frac{31}{66.5} = \text{about } \frac{3}{6}.$$

Beside this advantage in respect to cost of transportation, the potash in the muriate can be sold to the farmer at a lower price than that in the sulphate, because enormous quantities of the muriate exist ready formed in the Stassfurt mine, and can readily be extracted thence at trifling cost, whereas more labor and skill have to be expended in procuring sulphate of potash, even that of no more than tolerable purity.

Manifestly, purified articles are to be preferred to the crude minerals, in so far as this country is concerned, because of the cost of freight.

Stassfurt Salts seldom repay their Cost.

It is a curious fact, brought out by European experience, that, while phosphatic and nitrogenous fertilizers often repay their cost at once, and sometimes in a very striking way, dressings of plain Stassfurt salts have, as a general rule, given little or no money profit in fertile regions, excepting in the case of tobacco, and sometimes in the case of potatoes grown for table use.

When applied to clover, to beets, and even to grain, the potash salts improved the appearance of the crops and increased the burden of them, but in very many instances not to a profitable degree. Sulphate of potash has perhaps, on the whole, done rather better than the chloride; but, with the exception of tobacco, and perhaps potatoes, and sometimes on beet farms and moorlands, it has failed to yield the hoped for profit.

Ashes better than Potash Salts.

In one word, experience has proved that the Stassfurt fertilizers, used as such, are decidedly inferior to wood ashes. The explanation seems to be, that the sulphate and the chloride are devoid of the alkaline quality which is so marked a peculiarity of carbonate of potash, which, as is well known, is the effective agent in wood ashes. And, in point of fact, European experience has shown that the Stassfurt salts answer a better purpose when they are applied to marled land, or when they are used in conjunction with lime.

Undoubtedly there is still much to be learned as to the best ways of using both sulphate and muriate of potash; but it will be well meanwhile to act upon this lime hint, and to study the plan of making composts with peat and a mixture of lime and muriate of potash, as has been already suggested. It may be true withal, that small additions of potash salts and other fertilizers to barnyard manure, used in half its usual quantity, may be for certain crops an economical mode of application. The lack of profit above mentioned was in cases where potash salts were used, either by themselves, or in conjunction with other commercial fertilizers.

It needs to be said, however, that, when a mixture of lime and muriate of potash is used, there will naturally be produced more or less chloride of calcium, which is hurtful to some plants, and which, as Mayer has urged, may "bind" the land in some cases. It has not yet been determined whether this particular form of binding would always be hurtful for all kinds of soils. This is a point which might well have been talked about with those old farmers who formerly made and used composts with lime and salt. The binding could perhaps be avoided by applying the mixed fertilizers in autumn, for spring crops; and so giving time for the chloride of calcium to leach out of the land. It is not at all clear that this binding may not be due to carbonate of potash formed in the soil by the reaction of the potassium chloride on limestone.

Sulphate of Potash may react well upon the Soil.

Heiden has argued in a somewhat similar way, that sulphate of potash may perhaps generally do better service than the chloride, because it produces a better class of compounds than the latter by reacting on the soil. Such useful compounds as gypsum and sulphate of magnesia may be produced when sulphate of potash acts upon loam, while from the action of chloride of potassium come the chlorides of calcium and of magnesium, which may readily do harm to plants.

In this sense, it might be said therefore, even of the sulphates of low grades, that, in spite of their being contaminated with chlorides, they are comparatively speaking meritorious, and somewhat in proportion as the amount of sulphate of potash contained in them is larger. There is withal a good deal of field experience which goes to support the view that the low-grade sulphates are on the whole better than the mere chlorides.

Muriate of Potash diffuses tolerably easily.

There is one advantage to be credited to the chloride, however, in that it diffuses in the soil rather better than the sulphate. Potash is so readily fixed by the double silicates in loam, that it is not easy to secure a proper dissemination of the potassic fertilizers. No matter how deeply they may be ploughed under or harrowed in, the potash is apt to be absorbed and bound at precisely those spots where the particles of the fertilizer first came in contact with the earth. But this is a great disadvantage in many cases, especially where it is desired to manure the subsoil evenly, in anticipation of growing deep-rooted crops like sugar beets or clover.

Experiments have shown that the potash in the chloride is fixed decidedly less easily and less rapidly than that in the sulphate, so that a better diffusion may be had by means of it. Unfortunately, the chloride is not applicable for the growth of sugar beets. But the crystalline double sulphate of potash and magnesia, already mentioned, appears to be able to diffuse potash in the soil even better than the chloride. It is, moreover, a pure substance, free from chlorides, and on this account specially worthy the attention of beet-root and tobacco growers. In such cases as this, and when mixtures of Stassfurt salts and lime are used, the fertilizer will naturally be applied in autumn, or as long as possible before a crop is to be planted on the land.

Experiments on the Diffusing of Potash.

Treutler has made an extended study of the question how best to hinder or counteract the fixation of potash by the soil, so that this fertilizer may be made to diffuse itself into the subsoil and through all parts of the standing room of crops. He found that bone-meal exerted a decided influence to hinder the fixation by the soil of the potash in sulphate, carbonate, nitrate, or chloride of potassium ; and that several other fertilizers had some power to hinder the fixation of potash. Several saline fertilizers decidedly hindered the fixation of potash from carbonate of potash in particular. Farmyard manures of various kinds hindered the fixation of potash from the sulphate and the chloride, while they increased the fixation as regards carbonate and nitrate of potash.

Next to bone-meal, humus seemed to have the most marked solvent action when used with sulphate or with chloride of potassium, but it increased the fixation decidedly as regards carbonate of potash, and slightly as regards nitrate of potash. A mixture of humus and carbonate of ammonia had in general less solvent action than humus alone, or even than carbonate of ammonia by itself. Carbonic-acid water did not exhibit much solvent action, perhaps because the carbonic acid speedily escaped from it on coming into contact with the soil.

Nitrate of soda, used in conjunction with sulphate, carbonate, or nitrate of potash, increased the diffusion of the potash appreciably, but it did not do so when used with chloride of potassium. Gypsum, Epsom salt, and especially superphosphate of lime, had some solvent action, excepting when used with nitrate of potash. But chloride of sodium exhibited very little solvent action in any case.

. The fixation of potash from chloride of potassium was hindered by bone-meal, humus, manures, dung liquor, carbonate of ammonia, superphosphate, gypsum, Epsom salt, and carbonic-acid water. Indeed, with the exception of common salt and nitrate of soda, all the substances tried by Treutler promoted the diffusion in the soil of the potash in chloride of potassium. It was noticed, as had been done before by other observers, that in general the fixation of potash from a solution of the chloride is less complete than it is from the sulphate and carbonate, or even from the nitrate.

Practical Rules for applying Potash Salts.

In default of any extended practical experience with the Stassfurt fertilizers, and their known inability to repay an immediate money profit in most cases, it will probably be well not to apply large quantities of them at any one time. The amount that a judicious laborer would naturally scatter from his hand when sowing one of these salts upon a field would probably be a useful application to that crop in a rotation which stands in special need of potash. It appears that the muriate is often applied at the rate of 125 to 250 lb. to the acre, and kainit at the rate of 700 to 900 lb., usually in conjunction with other fertilizers. German dealers in fertilizers recommend that muriate of potash should be applied to heavy soils in autumn, and to light or sandy soils in early spring.

As regards the profitable use of potash salts for fertilizing potatoes, Bretschneider has insisted that, although much depends upon the mode of their application, moderate dressings of the Stassfurt fertilizers are decidedly useful. In so far as mere increase of crop is concerned, he holds that it does not much matter whether the fertilizer is used in the form of a sulphate or of a chloride, provided as much potash is applied to the land in the one case as in the other. He urges that potash salts should be strewn broadcast after the land has been harrowed flat, and then be worked in slightly with a smoothing harrow before any furrows are drawn, or drills marked out for the reception of the seed. By proceeding in this way an increase of crop may confidently be looked for.

On the other hand, potash salts should never be put into the hills where they might come in contact with the seed potatoes, nor be strewn in the furrows, since they are apt to hinder the sprouting of the seed and to destroy the young sprouts. Nor should the salt be strewn as a top-dressing, for in this case much of the fertilizer would be left where the rootlets can have no proper access to it.

Under the head of Soda, it will be seen that many plants can bear an application of common salt or of sea-water when mature which would kill them if they were young. The same remark is true of the Stassfurt salts, especially, it would appear, of the muriate; and it has been recommended that, in applying this compound to root crops, it should be worked into the soil at the time of the first or second hoeing, in order to be sure that none of it can come into contact with the young plants.

Multitudes of field experiments with potash salts have been reported in the German journals, and the results of them vary not a little. The following table of results obtained by Stoeckhardt may serve in some sort as an epitome of the matter. The fertilizers were applied in this case to potatoes on worn-out land. It was a light sandy soil charged with humus. Tubers were harvested from 1½ acres of land as follows, in German pounds: —

	Weight of Crop.	Per Cent of Starch.
600 lb. nitrate of potassium	12,340	23.0
" sulphate "	11,150	21.6
" carbonate "	10,720	24.2
" chloride "	8,850	20.6
" tartrate "	6,640	24.0
" phosphate "	5,950	24.0
No manure	4,840	23.2
600 lb. silicate of potassium	819[1]	

Chlorides hinder Tobacco from Burning.

The objection to chloride of potassium as a manure for tobacco depends upon the fact, that leaves of this plant which have been grown upon land rich in chlorides will not burn readily when dry, apparently because the chlorides tend to prevent a certain swelling or puffing up of the ashes in the half-burned tobacco which is favorable for bringing the particles of carbon into intimate contact with the air. Numerous experiments in proof of this peculiarity of the chlorides have been recorded. The following, by Nessler, are among the most recent of them. A number of individual tobacco plants growing in fields in two different townships were watered at the end of July with solutions containing each 15 grams of the salt to be tested. After the harvest the leaves were analyzed, and tested as to their power of holding fire.

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[1] In this case the plants were distressed.

EXPERIMENTS IN CARLSRUHE.

Kind of Tobacco.	Kind of Fertilizer used.	The Leaves glimmered Seconds.	Ashes.	100 Parts of the Leaves contained Carbonate of Potash.	Chlorine.	Water.
Maryland.	No manure	36	. . .	. . .	. . .	. .
"	Chloride of potassium . .	9	30.8	0.83	1.14	. .
"	Sulphate " . .	43	28.0	1.10	0.43	. .
".	Nitrate " . .	62	. . .	. . .	. . .	. .
Java.	No manure	43	. . .	. . .	. . .	. .
"	Chloride of potassium . .	20	32.6	0.83	1.42	. .
"	Sulphate " . .	67	30.4	0.37	0.71	. .
"	Nitrate " . .	31	28.2	0.64	0.71	. .
Nuremberg.	No manure	9	. . .	. . .	. . .	. .
"	Chloride of potassium . .	14	38.9	0.20	1.63	. .
"	Sulphate " . .	15	25.7	1.40	1.56	. .
"	Nitrate " . .	31	21.1	1.65	0.43	. .
EXPERIMENTS IN SECKENHEIM.						
Gundi.	No manure	8	. . .	. . .	. . .	. .
"	Chloride of potassium . .	5	19.9	0.60	2.13	12
"	Sulphate " . .	31	18.9	0.42	1.50	14
"	Nitrate " . .	45	17.2	1.57	2.20	14
"	654 kilos potash superphosphate and 2,180 kilos wool dust to the hectare . .	19	16.0	1.33	1.24	13
"	33 wagons farm manure and 300 kilos potash superphosphate	22	18.7	2.30	1.49	14
"	32 wagons farm manure and 30,400 litres dung liquor	17	18.8	3.80	1.35	15
"	25 wagons farm manure and 19,300 litres dung liquor	7	18.0	2.90	1.49	12
"	15 wagons farm manure and 15 wagons night-soil . .	173	19.9	3.22	0.71	13
"	40 wagons farm manure to the hectare	8	23.1	1.84	2.00	15

It appears that, with one exception, the application of chloride of potassium diminished the combustibility of the tobacco. One of the most remarkable results is the last item but one in the table, for night-soil usually contains a considerable proportion of chlorides, and is thought to be apt to injure the combustibility of tobacco. Nessler suggests that in this instance the preceding crop (mangolds) may have used up whatever chlorides there were in the field, and have left the soil comparatively free from them at the start.

The original experiments of Schloesing are given in the following table. They were made on poor sandy soil that was somewhat calcareous, and clayey enough also to be somewhat tenacious. The soil contained very little chlorine, sulphuric acid, or potash. One interesting point which these experiments illustrate is, that while sulphate of potash gives much potash to the plants, very little sulphuric acid is taken up by them. The result is similar to that obtained by Boussingault in his experiments with gypsum.

No. Plot.	Kilos of Fertilizer to the Hectare.	100 Parts of the Leaves, containing 10% of Moisture, contained Parts of					Combustibility of Cigars made from the Leaves.
		Potash.	Lime.	Magnesia.	Sulph. Acid.	Chlorine.	
1	No manure	1.04	7.78	0.99	0.99	0 70	Almost incombustible, did not hold fire.
2	8,300 flesh and 11,500 washed peat	0 98	7 48	0.81	0.98	0.55	" "
3	666 sulphate of potash	2.66	6.58	0.78	0.97	0.43	Readily combustible, held fire 3 minutes.
4	570 chloride of potassium	1.74	7.17	0.78	0.87	1.64	Slightly combustible, held fire 1 minute.
5	778 nitrate of potash	2.13	6.28	0.64	0.79	0.88	Readily combustible.
6	265 carbonate of potash	1 65	7 34	. . .	0.96	0.44	Combustible, held fire 3 minutes.
7	530 " "	2.24	6.24	0.65	0.84	0.42	" "
8	1,060 " "	2.50	6.61	. . .	1.05	0.54	Readily combustible
9	432 chloride of calcium	1.16	8.47	0.97	0.85	1.77	Absolutely incombustible.
10	218 chloride magnesium	0.82	8 29	1.09	0.77	1.69	" "
11	500 silicate of potash	1.89	7.74	0.92	0.98	. . .	Moderately combustible, held fire 1 minute.
12	1,000 " "	1.99	7.44	0.78	1.06	0.50	Passably combustible.

It will be noticed that the plots 1, 2, 9, and 10, to which no potash was applied, all gave bad burning tobacco; that those treated with chlorides, 4, 9, and 10, gave tobacco that contained three times as much chlorine as the others, showing that this element is easily assimilated; and that the tobacco which contained this large proportion of chlorine burned badly.

Stassfurt Salts may preserve Manure.

Several of the low-grade minerals and products from Stassfurt are well suited to be used instead of gypsum in horse and cow stables, and in sheep stalls, to keep them sweet; and even on dung-heaps, to hinder that form of putrefaction which occasions loss of ammonia. They may be used, perhaps even more economically than gypsum, to "hold" ammonia, as the common saying is; for, as is well known, chloride of magnesium (and chloride of calcium also) has the power to absorb and fix very considerable quantities of ammonia. Eichhorn found, for example, that one gram of anhydrous chloride of magnesium could absorb 1,187 c. c. of ammonia gas (and one gram of chloride of calcium 1,437 grams), while a gram of spruce charcoal absorbed no more than 105 c. c. of ammonia.

Fittbogen has made numerous trials with stall-fed sheep, at temperatures ranging from 54 to 69° F., to determine how much of the nitrogen in the fodder was retained in the manure according as one or another of the preservatives was scattered upon it. He was well satisfied with their action, having obtained results which are given, very much condensed, in the following table. The following amounts of the fodder nitrogen were found in the manure, when there was used, —

	Per Cent.
No preservative, from	71 to 82
0.10 kilos gypsum to each sheep, per day, from	88 to 90
0.08 " kainit " " "	84 to 94
0.12 " carnallit " " "	87 to 97
0.06 " refuse salts from the Stassfurt factories	90

In practice, it would probably be sufficient to use half a pound per diem either of kainit, or carnallit, or gypsum, for each horse or cow, or for every 10 sheep. The potash compounds would be just as valuable when used as fertilizers indirectly in this way, as if they were put upon the land as such.

Troschke found that while carnallit strewn in stables absorbed 9% of ammonia, kainit absorbed only 4½%; though, as he remarks, the large proportion of chlorides in carnallit might sometimes be objectionable. Maercker also has suggested that it will be well to avoid those salts which are rich in chlorides in cases where the manure is to be used for tobacco or sugar beets. He urges also, that the tendency to absorb moisture from the air which is exhibited by the salts which contain much magnesium chloride may make them inconvenient of application in some cases.

Morren found that the loss of nitrogen from decaying horn-meal was almost wholly prevented when 10% of kainit was mixed with the horn. The mixture remained neutral instead of becoming alkaline, as happened when the moistened meal was allowed to ferment without the kainit.

The results given in Fittbogen's table manifestly refer to tolerably fresh manure. Other experimenters have shown that the preservative influence of kainit and gypsum is not necessarily permanent, since considerable losses both of the dry matter and the nitrogen in the manure thus treated have been noticed after a few months' time. Troschke found at the end of 3 months that a loss of 20% of the dry substance and 10% of the nitrogen had occurred in manure which had been mixed with kainit, and that 19% of the dry substance and 32% of the nitrogen had disappeared from manure that had been mixed with gypsum. He found that gypsum fixed ammonium carbonate more freely than either of the Stassfurt salts, and that among the latter kieserit was the most effective. Heiden also found that kainit was less effective than gypsum for fixing ammonium carbonate.

Value of Potashes.

American potashes, which consist essentially of a mixture of hydrate and carbonate of potash, and usually contain some 60% of real potash, may be had nowadays at about 5 cents the pound at wholesale. Hence the pound of real potash in them would cost about 8 cents, while it can be obtained for 4 or 5 cents in the form of muriate of potash. But in view of the ability of the caustic alkali to decompose and dissolve bones, and to excite fermentation in heaps of peat, weeds, and other vegetable matters, as has been explained under the head of Composts, it may after all be best, in some cases, for the farmer to buy what potash may be needed for his land in the shape of "potashes," rather than in that of sulphate or of chloride of potassium. Although the real potash (K_2O) in the "potashes" may cost much more money than it would if bought in the form of a neutral salt, it may nevertheless be true, perhaps, that the caustic alkali may be the cheaper substance for the farmer to buy, because it is really a source of two kinds of power. After it has made the peat, or bone-meal, or weeds, or what not, ferment, it is still as useful as ever as a source of potash for the crops. "Potashes" are here specially insisted upon, because they can always be had everywhere; though of course, if wood ashes can be got, the alkali in them ought to come at a cheaper rate, because ashes are a crude unmanufactured material, upon which no labor has been expended except the cost of collecting and transporting them.

Nitrate of Potash.

Nitrate of potash is a powerful manure, as has been said under the head of Nitrogen Compounds. It is often formed in the soil, no doubt, and does good service there in feeding crops, but it has hitherto rarely been employed as a commercial manure because of its high price; i. e. it has been worth too much for other purposes, such as the manufacture of gunpowder, to be available for agriculture. Owing, however, to the great reduction in price which has resulted from the working of the Stassfurt mine, nitrate of potash is nowadays used with advantage in cultivating tobacco. Here the quality of the crop is of paramount importance, and it "pays" to feed it with the best. So, too, excellent potatoes may be grown by manuring with nitrate of potash.

The old plan was, instead of using nitrate of potash directly, to apply a mixture of nitrate of soda and muriate of potash; and for grass and grain this mixture is well enough, but the chloride of potassium is objectionable both for potatoes and tobacco, as well as for sugar beets, in that it is apt to hurt their quality. Hence the modern use of nitrate of potash in these special cases. It may be asked, however, whether a mixture of nitrate of soda and sulphate of potash of the highest grade might not be used with advantage instead of pure saltpetre. In Dreschler's field experiments on potatoes, it appeared that, while potash in the form of nitrate of potash did much better service than that in kainit, the chief gain consisted in the fact that the nitrate tubers were of larger size than the others.

Saltpetre Waste.

At gunpowder works, and other places where crude saltpetre is refined, a waste product containing some sulphate of potash and a little nitrate of potash, together with a good deal of common salt and sulphate of soda, may be procured. As has been explained under the head of Nitrates, this waste product often has considerable value as a fertilizer, though it needs to be analyzed because different samples of it vary widely as to their composition.

Potash aids in translocating Starch.

As will be explained in another connection, it has been discovered that potash plays a very important part in vegetable physiology, in that it serves as a means of enabling starch to move from one part of the plant to another. Moreover, those juices of plants which are noticeably sour, such as lemon juice, the sap of rhubarb stalks and sorrel leaves, the juice of sour apples, gooseberries, grapes, and the like, commonly contain an acid salt of potash. In most such cases the acid combined with the potash is either citric, malic, tartaric, or oxalic.

It has been noticed withal, that tobacco leaves well charged with the potash salts of the vegetable acids now in question burn readily, in a manner very unlike leaves that contain chlorides. Hence one advantage in feeding tobacco plants with appropriate potassic fertilizers, over and above the benefits due to any increase of the amount of crop. The presence of much carbonate of potash in tobacco ash, as set forth in the table on page 129, is an indication that considerable quantities of the organic compounds above mentioned (or of nitrates) were contained in the leaves. When subjected to heat, these organic potash salts swell up during the process of decomposition so that the charcoal is left in a spongy, easily combustible condition, the final product of their decomposition being carbonate of potash.

CHAPTER VIII.

MAGNESIUM COMPOUNDS.

MAGNESIUM is one of the elements absolutely necessary for the growth of plants. In the absence of it crops cannot prosper. But since magnesium compounds are found in tolerable abundance in most soils of fair quality, and in all soils that are dressed with stable manure, comparatively little attention has been given to their employment as fertilizers.

It is true, indeed, that the amount of magnesium taken up by plants is rather large. Thus, the ashes of wheat-grain contain about 12% of magnesia against 3% of lime, and the ashes of peas 8% of magnesia to about 4% of lime, and so with various other seeds and grains. It is noteworthy, moreover, that a comparatively large proportion of magnesia accumulates in the grain or seeds of the plant, and is in that way liable to be sold in the crop and carried away from the land. But it is also true, that magnesia compounds are widely diffused in nature.

Small quantities of silicate of magnesia occur in many rocks, such as granites, syenites, dolerites, and the like. All limestones contain more or less magnesia, and the so-called "dolomites," or magnesian limestones, contain a great deal of it. Soapstone, serpentine, and the talcose slates are magnesian rocks. There is magnesia in ashes also, in bones, and in sea-water. It is consequently an exception to the general rule when a soil is sterile through absence of magnesia.

Nevertheless, it may sometimes be true that the application of a small quantity of a magnesia compound to land will improve it. This has been seen occasionally in Germany, as a result of the application of the potash-magnesia minerals from Stassfurt. It was shown long ago by Stoeckhardt, as the result of very extended experiments with magnesian limestone from the low lands of Saxony.

Modes of Action of Magnesia.

It is possible that magnesia when applied as a manure may act directly by serving as food for the plant, or it may be that it will act indirectly by expelling potash, or ammonia, or lime from the aluminous double silicates of these substances which exist in the soil. When applied in the form of a magnesian limestone, for example, the magnesia may perhaps help the lime to effect the expulsion of the foregoing ingredients of plant-food from the hydrous silicates that hold them. In other words, it may happen that the decomposition of the silicates is brought about more readily by a mixture of lime and magnesia than by lime alone.

The magnesian limestone, just now mentioned as having been examined by Stoeckhardt, gave a quicklime containing about 60% of lime and nearly 40% of magnesia; and it was found, as the result of wide and long-continued experience in Saxony, that this lime is a stronger and a more enduring fertilizer than that obtained from purer limestones. It may well be true, however, that the final effect of such lime may be mechanical rather than chemical. It may work to alter the texture and capillary condition of the soil, as will be seen under the head of Lime. It is easy to believe, at all events, that the more ready solubility of carbonate of magnesia in carbonic-acid water, as compared with that of carbonate of lime, may give to magnesian limes a real superiority over pure limes, as ameliorants of heavy land.

The argument is not infrequently urged, that phosphoric acid is specially needed by plants, since it accumulates in their seeds. But manifestly the same reasoning would apply to magnesia also, which, as has just been stated, is found in seeds in larger quantity than occurs in the other parts of plants. The only difference between the two cases is, that phosphoric acid is rare, in the sense that it is sparsely distributed, while magnesia is abundant in most rocks and soils.

Magnesia sometimes Hurtful.

Doubtless one reason why so little has been said or done in favor of classing magnesia among fertilizing substances, is due to an old belief that it is liable to kill plants. This notion seems to have been based on the analyses of English chemists made at the beginning of this century. It appeared from the analyses in question, that certain limestones, which had sometimes been found in practice to injure crops, contained magnesia. Tennant moreover found, on mixing calcined magnesia with soils in which he sowed different kinds of seeds, that the plants either died, or were unhealthy, or vegetated in a very imperfect manner.

Hence magnesia immediately fell into bad repute, in spite of the fact that Sir Humphry Davy, on inquiring into the matter, found that there were cases in which these very magnesian limestones were used with good effect in field culture; and that a number of specimens of limestone, which had been sent to him by farmers as peculiarly good, were found to contain magnesia. Furthermore, Davy called attention to the fact, that, in one of the most fertile tracts in Cornwall, the Lizard, the soil contains much magnesia. "The Lizard Downs bear a short and green grass," he says, "which feeds sheep producing excellent mutton; and the cultivated parts are among the best grain lands in the county." Davy made experiments also by growing plants in soils mixed with magnesia compounds, whence it appeared that, although caustic magnesia is injurious when present in considerable quantity in the soil, it may be beneficial when mixed with peat, or when it exists in the form of a carbonate.

That there was some truth, however, in Tennant's experiments, and in the prejudice against magnesia, has appeared recently from Knop's experiments in water culture. Knop finds that in the solutions employed in water culture the magnesium salts do manifest harm unless they are accompanied by an abundance of lime, potash, or ammonia salts. By themselves, the magnesia salts bring about a peculiar alteration in the roots of the plants, and in that way soon cause the death of the plants.

Knop suggests that the bad effects sometimes produced by magnesia in field culture can probably be prevented by using in conjunction with it a sufficient quantity of lime. He makes the further suggestion, that, in view of the extremely easy solubility of chloride of magnesium, and the possibility of this salt's forming in some soils when they are dressed with chloride of potassium, that the last-named salt may be inferior as a fertilizer to sulphate of potash, which would never produce any such hurtful salt. But, as has been suggested already, this very formation of magnesium chloride in the upper layers of the soil might sometimes be advantageous, since it would be likely to react upon the potash silicate below, and to set free potash from it.

Kinds of Magnesian Fertilizers.

There is but little to be said as to the different forms in which magnesia may be applied to the land. Lime rich in magnesia can usually be obtained readily. It would not be difficult to reduce dolomite to powder. If the use of it were found to be advantageous, this powder could be supplied in abundance at a very cheap rate.

The Stassfurt minerals and the products obtained from them are always to be had. Were it not for the probability that lime made from dolomite has peculiar merit for improving the texture of soils, it might be said at once, and without reservation, that in some one of the potash-magnesia products from Stassfurt may be found the cheapest and the best source of magnesia. In case of need, it would be easy to treat soapstone or serpentine with oil of vitriol, and so get an impure sulphate of lime and magnesia. Epsom salt also is obtainable at cheap rates from sea-water, and as a residuary product in the manufacture of carbonic acid gas from magnesite by means of sulphuric acid; and of late years chloride of magnesium is said to be procurable almost as a gift at Stassfurt.

The double phosphate of magnesia and ammonia, which is obtainable by adding a magnesium salt and some alkali to putrid urine, should likewise be borne in mind. The preparation of this compound has often been proposed as a device for saving some part of the phosphoric acid and ammonia now lost from cities, although, owing to the bulky character of the liquid to be operated upon and to sanitary considerations, the process cannot be regarded as one of general applicability. There can be little doubt, however, that sulphate of magnesia (common Epsom salt), or chloride of magnesium, or Abraum salt, may be added with advantage to the pit into which the drainings of the dung-heap flow, in cases where such pits are maintained.

It is plain that the farmer may free his mind from all care as regards magnesia considered as plant-food, by dressing his fields lightly, once in a while, with one of the low-grade Stassfurt fertilizers. Even the highest grades now obtainable contain more magnesia than crops need.

In speculating as to the condition in which magnesia may exist in the soil, the compounds specially to be considered are the carbonate, which is, comparatively speaking, readily soluble in carbonic-acid water, the double (and simple) silicate, humate, and phosphate, and possibly even the double phosphate of magnesia and ammonia.

CHAPTER IX.

LIME AND LIME COMPOUNDS.

The theory of the use of lime as a manure is a subject full of interest and importance, as well as of doubt and apparent contradiction. In some regions, the farmers are seen to apply lime to the land wellnigh universally, and in such quantities, indeed, that at certain seasons of the year the whole surface of the country is made white with it; while in other places, as in the vicinity of Boston, for example, it is easy to perceive that lime is held in small esteem by practical men.

It is hard to say positively why opinions should differ so widely, or to discover all the reasons which have determined the observed variations of practice. In one word, the subject of liming land is not yet thoroughly understood in all its bearings. It is not unlikely, however, that the mystery might even now be explained in good part, if not wholly, if some competent person would take the time and trouble to observe the facts in several localities, and to study the history of this particular branch of agriculture in the light of modern science. At all events, the problem could doubtless be solved if the results of the old experience were once thoroughly sifted, and properly set forth and formulated so that experiments could be devised understandingly, by which to settle the obscure points.

As matters actually stand, the student is met at the threshold of the inquiry by so many different statements, so many possibilities and probabilities, that the subject is made to seem less clear than it really is. As has been said, the contrasts between the current methods and practices of farmers in respect to the use of lime are very remarkable. Why is it, for example, that so little lime is used in Eastern Massachusetts? and why is it that such enormous quantities of it are used in other districts, such, for example, as some parts of Pennsylvania, of France, and of Germany, which have fallen under my own observation? At New York, Brooklyn, and New Haven the gas companies are said to sell their spent lime for almost as much as the fresh lime cost them, but in Boston no one will take the spent gas-lime as a gift.

Indifference towards lime, or objection to it, is by no means peculiar to this particular locality. It is notorious that in some parts of the world landlords have often absolutely forbidden their tenants by contract from using lime, and the employment of it in agriculture at the present day cannot in any sense be regarded as a general practice.

Another striking diversity is seen in the fact that most German writers claim that lime gives its best results on heavy land, while the French often urge that the proper place to apply lime is upon light open soils. The impartial reader is in either case naturally inclined to believe positive affirmative statements such as these; and it is not easy to escape the conviction, that in both countries the customs have resulted from practical experience, and that in general the farmers are justified in their practices.

Manner of applying Lime.

The favorite way of applying quicklime is to bury it in little holes in the moist earth of the field, or to make little heaps of lime upon the surface of the land and cover them with earth. In either event the lime soon slakes and falls to a fine dry powder which is then spread upon the surface of the land. In a dry time the heaps of lime would need to be moistened with water, but usually the dampness of the soil is all-sufficient. On stiff land from 4 to 6 tons of quicklime are applied to the acre, sometimes even 12 tons.

A Scotch writer has recently described his practice as follows. Plough oat stubble as soon as convenient after removal of the crop. Next spring harrow across the furrows, as soon as may be practicable, to smooth the land; lay out the quicklime in heaps six yards apart, and cover the heaps immediately with the very damp soil. In 24 hours' time the lime will have fallen to fine powder, which must be spread speedily to avoid the risk of rain. Finally, harrow in the lime with a heavy harrow. Turnips are found to succeed well after this treatment, and to be comparatively free from the finger-and-toe disease.

Sometimes the lime is applied to grass-land, commonly when the grass is young, or to young clover, care being taken to have the material thoroughly slaked to a fine dry powder, and to spread it evenly.

Modes of Action of Lime.

Looking at the question of the use of lime from the theoretical point of view, it is plain that a certain proportion of lime is necessary to the plant. Lime is a substance that can no more be spared than potash, or magnesia, or than phosphoric or sulphuric acids. Some of it must be present in the soil, or no crop can grow. But, in so far as the immediate requirements of plants in this sense are concerned, a few pounds of any lime compound to the acre would satisfy them, and there is already enough, and more than enough, lime in almost every cultivable soil.

Lime is Abundant.

Indeed, lime is one of the most abundant of substances. It has been estimated that not less than one sixth of all the rocks on the surface of the globe are limestones, and that the metal calcium forms as much as one sixteenth of the solid crust of the earth. Vast tracts of country are composed almost entirely of limestone, and there are wide ranges of soil that is wellnigh wholly calcareous. There are great beds of gypsum also here and there, and scarcely a rock can be found that does not contain lime as an essential ingredient. All the ordinary granitic rocks contain calciferous silicates. In the older part of Boston, the very waters of the wells are "hard," because they are charged with gypsum; and in many localities, where limestone abounds, all the waters are hard, from the presence in them of bicarbonate of lime.

It may often happen, no doubt, in sandy regions, and in soils which have resulted from the decomposition of certain sandstones, slates, and other rocks poor in lime, that neither the soil itself, nor the water which percolates through it, contains enough lime to serve as nourishment for plants; but in almost every such instance there is a still greater deficiency of other fertilizing materials, such as phosphoric acid and potash, than of lime, and the use, not of lime, but of some general manure, like that from the farmyard, will be indicated. In any event, if it were wished to give such a soil lime, it would likely enough be better to apply plaster of Paris, or bone-meal, or superphosphate, or some compost made with lime, rather than mere quicklime.

Income and Outgo of Lime.

This point can be readily illustrated by contrasting the amount of lime in ordinary soils, or even in the poorest soils, with the quantities of lime that are taken off in crops. It will be seen at once that cultivated soils commonly contain a great superabundance of lime over and above all that can possibly be needed for the mere purpose of feeding plants. Thus, if it be assumed that an acre of land taken to the depth of one foot weighs 3,250,000 lb., and that the soil contains no more than one tenth of one per cent of lime, which, as the records of soil analyses show, is an extremely low estimate, there will still be no less than 3,250 lb. of lime to the acre. But in a crop of

18 bushels of wheat and 2,000 lb. of straw there are only some 6 or 7 lb. of lime.
12 bushels of peas and 1,200 lb. of straw, 28 or 29 lb. of lime.
120 bushels of potatoes and 3,000 lb. of tops, 20 lb. of lime.
375 bushels of mangolds and 6,000 lb. of tops, 25 to 28 lb. of lime.
In 5,000 lb. of clover hay there are 100 lb. of lime.

Moreover, wherever farmyard manure is used, quantities of lime as considerable as those taken off in crops are commonly returned to the land, and in most commercial fertilizers also there is more or less of it. Voelcker's analysis of six months' rotted farmyard manure shows 2% of lime; that is to say, a single cord of such manure, even if it weighed no more than three tons, would carry to the land 120 lb. of lime. 100 lb. of guano contain some 10 lb. of lime; 100 lb. of bone-meal, about 27 lb.; 200 lb. of plaster, more than 60 lb.; and so on.

From all of which it appears that lime cannot be accounted a fertilizer of direct action. Consequently, in seeking to explain the benefits derived from lime, special attention must be given to the physical and chemical actions of this substance upon the soil itself, and upon various constituents in the soil.

Liming often improves Tilth.

There is no question, either that lime may, or that it does actually, exert a very powerful influence to alter the mechanical condition or texture of soils to which it is applied. Sometimes this alteration must be beneficial, and at other times detrimental; and this circumstance is of itself sufficient to explain why lime is esteemed in some districts and not in others.

A very little attention to the way in which lime acts in mortar will make this assumption clear. If a thick, smooth paste of slaked lime and water be spread thinly upon the surface of a stone, or upon a piece of wood, and left to dry there, it will be found that the film of dried lime adheres to the smooth surface with great tenacity; and since in the process of drying a good part of the lime has changed to the state of a carbonate, it cannot readily be washed away even. A familiar example of this adhesion is seen in ordinary whitewashing.

It is essential to the success of this experiment that the layer of lime should be thin; otherwise, it might crumble upon itself in drying. In case the paste be spread upon a porous solid, such as a brick, for example, instead of the wood or stone, it will be noticed that the lime adheres to it still more strongly than to the smooth surface, since some part of the layer has struck root, as it were, in the pores; and in case dry loam were taken instead of the brick, the adherence would doubtless be still stronger.

Now mortar is nothing more than a lime paste, into which so many little stones (grains of sand, that is to say) have been put that no more than a thin layer of lime shall be in contact with each one of these stones. But when a field is dressed with lime, the lime paste formed by the union of the lime with water must adhere to the particles of soil in a manner analogous to that now in question, and the physical character of the soil must be very much altered by this adherence. The power of the soil to lift water by capillary action will be changed, and in some cases it will be very much improved, while in other cases it will be diminished.

In the North of Scotland it has not infrequently happened that peaty and moorland soils, which are naturally light, have been "overlimed," as the term is; one symptom of the affection being that the land becomes too loose and open, so that it sinks under the foot and affords no proper support for the roots of grain plants. The inference is, that the texture of the soil has been hurt, so that it is no longer in a good capillary condition, and cannot bring water to the surface readily from below.

The geological formation called Loess, first by the Germans, but nowadays by everybody, affords a stupendous example of the binding power of lime. This extraordinary formation covers several hundred thousand square miles in Northern China, and larger areas in other parts of Asia. It covers an immense area in our own Western country. In China it is sometimes 2,000 feet thick, and in Europe and America it is sometimes 150 to 200 feet thick. Now this loess is a calcareous loam, which is easily crushed in the hand to an almost impalpable powder, and yet its consistency is such that it will support itself for years in vertical cliffs 200 feet high. On close examination, it is found to be filled with minute tubular pores, which branch downward like rootlets, and these pores are lined with carbonate of lime. It is to these tubes that the loess owes its consistency and its vertical internal structure. In China, in particular, the loess districts are extremely fertile plains. They constitute the grain regions of Northern China, which have been cultivated for more than 4,000 years, apparently with very little manure. The porosity of the soil permits the elevation of nutritive matters from a very great depth, whenever a rain has established a moist communication with the ground-water.

Flocculation by Lime.

Another kind of mechanical action, even more important than the foregoing, is found in the power of lime to cause the coalescence, or so-called "flocculation," of the finest particles of soils into coarser granules. It was observed some years ago by F. Schulze, that muddy liquids can readily be made clear by adding to them lime-water and certain other chemical agents. He noticed, in particular, that extremely minute particles of clay, such as will never settle from a mud-puddle, will, on the addition of small quantities of lime, or of lime compounds, speedily flocculate or coagulate into larger aggregations which soon settle out and leave the water clear. The sediment thus obtained is of much looser, lighter character than clay or mud which has settled by itself, and this looseness of texture or friability persists when the sediment is dried.

This observation has been repeated by Schloesing and by Hilgard, and it is now well known that lime has a very remarkable power to act in this way upon all extremely fine particles of matter, and thus to improve the texture of clays and silts and fine loams, such as would naturally be too muddy or cohesive.

It had often been noticed by experimenters, that, on seeking to wash out from soils the soluble matters that are contained in them, the first portions of wash-water flow off clear enough, but that the succeeding portions are cloudy from the presence of suspended matters, notably minute particles of clay. On encountering this difficulty Schloesing found that he could overcome it, at least for the soil he had in hand, by passing a current of carbonic-acid gas through the soil while he was washing it; and he concluded that the formation of bicarbonate of lime, by this device, was the cause of the filtrates remaining clear. Hence his trials of other lime salts, and of various saline solutions. He found that, while quicklime and the various salts of lime were the most efficient precipitants, magnesium salts were nearly as effective, but that potassium salts were weaker, and salts of sodium and of ammonium weaker still. Acids, such as sulphuric, nitric, and chlorhydric, have the power of coagulating clay liquor; but alkalies have not, at least not when they are dilute. Unless the solution of alkali be concentrated, it will not precipitate clay liquor, but will favor the retention of the clay in suspension. No matter what the precipitant, as soon as the coagulated clay has been freed from the substance that threw it down, it regains its power of remaining suspended in water, and it can again be precipitated therefrom on adding lime.

In some special instances Schloesing found that 2 parts of lime, in the form of chloride, nitrate, or sulphate of calcium, immediately caused flocculation in 10,000 parts of a turbid liquor that contained a good deal of clay; and that flocculation was still perceptible when the proportion of lime was only 1 part to 10,000 of the liquid, but ½ a part seemed to have no effect on the special liquor in question, not even in the course of six weeks.

Puddled and Granulated Soils.

As was explained under the head of Tillage, there are certain processes in the arts where the object is to make particles of clay or earth as fine and adhesive as possible, as in the processes of tamping, puddling, and kneading. But in agriculture it often happens that it is desirable to do away with the tamped, puddled, adhesive condition into which soils are apt to fall, and lime is one prime agent for effecting this result.

The importance of lime in this regard may be shown by a rather striking experiment of Professor Hilgard's, as follows. "Let any clay or tough clay soil," he tells us, "be worked into a plastic mass with water and then dried; the result will be a mass of almost stony hardness. But add to some of the same paste half a per cent of caustic lime and a diminution of plasticity will be obvious at once, even in the wet condition; and, on drying, the mass will fall into a pile of crumbs at a mere touch." Thus it is that by liming clay soils they may be made "warmer," "mellower," and of better tilth.

Schloesing found that lime-water was more effective than any other calcium compound for coagulating mud-puddle liquor, i. e. clay water; and both he and Hilgard find that no other chemicals are so powerful in this respect as the lime compounds. Hilgard made carbonic-acid gas bubble through a magma of limed clay for 24 hours to destroy the causticity of the lime, but the plasticity of the clay was not restored, not even after the mass had dried, for in this case nothing was done to break down the flocks.

Once get the fine particles granulated, no matter by what means, and they will stay so until they are subjected to kneading, tamping, puddling, or washing. This result agrees with practical experience. On some kinds of soils farmers find that the "lightening" effect of a liming lasts for years, and is never entirely lost. So too, it is known that marling produces similar lightening effects to lime, though the action of the marl is, naturally enough, weaker than that of the lime. The influence of the marl will depend on that of bicarbonate of lime formed by the solvent action of the carbonic-acid water in the soil upon the carbonate of lime in the marl. Whereas, in case land is limed, it is to be remembered that, since caustic lime itself is somewhat soluble in water, the solution of it (lime-water) will soak into the soil in all directions around each particle of solid lime, and so extend the limit of its influence.

Importance of Lime on Clays.

The improvement of the texture of clayey soils that results from the use of lime, and of lime carbonate, is a practical fact of the very first importance. The benefits derivable from such amelioration may readily be conceived on considering how difficult it is, generally speaking, to cultivate clays, and how much trouble has to be taken in order that trees may be made to grow on clays that are somewhat refractory. Mr. Emerson, in his "Report on the Trees and Shrubs of Massachusetts," has remarked that "the northern and southern sides of Boston are not essentially unlike in their natural features; yet the hills of Brookline and Roxbury, capped with hickory, and whose sides are clothed with oaks and pines, give the impression of a rich and happy country, of which only pleasant memories are carried away, while the bare hills of Chelsea suggest images of bleak and barren desolation." This statement may be emphasized by adding, that the bare Chelsea hills, like those of the neighboring bare islands in Boston Harbor, are composed of stiff, unfriendly, glacial clay; which, though easily "cleared" by the first "planters," and still esteemed to be good land for grass, is not well suited for the growth of young trees. The wooded heights of Roxbury and Brookline, on the contrary, are for the most part gravelly or rocky.

Prof. J. D. Whitney has insisted once and again that the extreme fineness of many prairie soils at the West is the chief reason why these prairies were bare of trees when first discovered.

Wicke, in publishing analyses of several very finely divided clayey silts from the Oldenburg marshes, which, though of excellent chemical composition, are notoriously infertile, — so much so, indeed, that the farmers when ploughing take particular care not to turn them up from the subsoil, — admits his inability to explain their barrenness, unless it depends on the fineness of their particles, and their consequent plasticity and liability to form stone-like clods in drying. Some of these soils have been improved by dressing them with gravel, and others by means of lime and by marl.

I have myself observed, in pot experiments, on attempting to grow plants in pipe-clay admixed with sand, that the fine particles of the clay seemed actually to clog the pores of the plant roots, and prevent their development. (See Bulletin of the Bussey Institution, 1884, II. 309.)

Lime may combine with Silicates.

It may be said further of lime, that it can act by uniting with the hydrous silicates in the soil so as gradually to expel from them potash, ammonia, or magnesia for the use of crops. Heiden has shown by experiments that the fact is as here stated. But experiments have also shown that gypsum can serve this purpose better than mere lime.

Lime and Humus.

Caustic lime may hasten the decomposition of organic matter in the soil, and, as has been said before, it may serve to decompose the inert nitrogen compounds of humus. This effect is probably one of the most important of those produced by lime. Townsend has mentioned the case of a Welch farmer, whose land had been a bog before it was drained, and consisted principally of dark-colored vegetable mould much of which was actual peat, who found lime to be a most excellent manure. He was accustomed to put most of his stable manure upon mowing-fields, and to use only lime for wheat, and in this way he obtained most abundant crops. He had two lime-kilns constantly burning for his own use. Townsend remarks, that "on this land I have counted 60 grains [of wheat] to an ear, not picked and culled out of many others as being longer than the rest, but taken by handfuls at random. . . . . On this land, lime as a dressing was particularly apt, because, as we know, it hastens the putrefactive process, and promotes the dissolution of vegetable substances, converting them quickly into vegetable mould."

Many writers have urged that lime, or rather lime carbonate, does good by promoting the formation of nitrates from nitrogenized organic matter, or from ammonia, within the soil; and recent experiments have shown that, as regards the carbonate at least, this view is correct. From a very early period, indeed, carbonate of lime has been considered to be an essential adjunct to the porous earth of saltpetre plantations, and it has long been known that nitrates are specially apt to form in limestone caves and upon walls plastered with lime. And, latterly, Warington has shown by experiments that the nitrifying ferment prospers exceedingly in presence of an excess of carbonate of lime, and indeed will hardly do good work without a supply of the carbonate.

Liming destroys Insects, Worms, and Fungi.

But while carbonate of lime is helpful for nitrification, lime proper, i. e. slaked lime, is regarded as a cure for some hurtful fungi. The liming of seed-grain to destroy the fungus which causes "rust" or "smut" has long been usual. The use of lime upon turnips, as a check to the finger-and-toe disease, has already been mentioned; and I can myself bear witness that I have grown exceptionally fair and smooth rutabagas during three consecutive years upon limed land at the Bussey Institution, though no farmer in the vicinity would venture to try to grow turnips year after year on the same land, because of their liability to the disease called "club foot."

Professor Voelcker has stated the matter as follows: "Every [British] farmer knows how essential lime is for the healthy growth of every kind of produce. On soils destitute of lime, most crops, and especially green crops, are subject to disease, and 'root-crops' are apt to fail altogether on such land, even if it has been liberally

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manured with dung or guano. Up to a certain stage, grain and roots grown under such conditions appear to thrive well, but as the season advances they sustain a check, and at harvest-time yield a miserable return. The cure for such failures, which are not uncommon where poor sandy soils prevail, is a good dose of lime or marl, and then, and only then, dung or guano may be applied to the greatest advantage. The most liberal application of farmyard manure of the best quality never produces so beneficial and lasting an effect on poor sandy soils, as when they have been previously well marled or limed."

It is not improbable in such cases that some part of the good done by the lime may be due to the destruction of insects and their larvæ, as well as earth-worms and worms of other kinds, and fungi of various sorts. Indeed, lime-water, lime, and mixtures of lime and salt (or, better yet, of lime and muriate of potash?) are often purposely used by gardeners for destroying slugs and worms; and there are good reasons for believing that lime might often be applied to the soil with advantage in farming practice also, on this account.

It must always be borne in mind, that slaked lime is appreciably soluble in water, and although this "lime-water" cannot be supposed to continue to exist very long in the soil after its formation, in view of the large quantities of carbonic acid which the pores of the soil contain, the liquid is still so destructive to animal life that there is good reason to believe that, while it does last, its action in this way may often be of considerable importance.

Liming corrects Acidity.

Liming is reputed to be excellent for correcting the acidity of sour land, and the idea is probable in itself, especially as regards situations where the lime is so used that it shall neutralize any large excess of free humic acid.

Cultivated soils, though sometimes neutral to test papers, as a rule exhibit a faint acid reaction; and experience with water culture has shown that slightly acid solutions are favorable for the growth of plants. But any excess of soluble acids in the soil would be highly detrimental. The acid would injure the plants directly, and destroy the microdemes which regulate the fermentation of humus, as well as dissolve out iron compounds to poison both microdemes and crops. Such acidity may readily be corrected by lime, and the good effects of lime upon sour meadows in particular may justly be credited to neutralization of their acidity. One noticeable effect of lime in such cases is the destruction of plants that thrive in bogs; the inference being that the lime has neutralized the chemical substances which such plants can, and English grasses cannot, support, and has so given the latter opportunity to grow.

Liming decomposes Organic Matter.

The use of lime to neutralize sour humus has been dwelt upon already under the head of Composts, and so has its power of promoting fermentation. Like the other caustic alkalies, it acts to excite the fermentation of organic matters, both in the compost heap and in the soil. Apparently one cause of the fermentation is the rapid disorganization of the vegetable matter by the strong alkalies; that is to say, the lime or other strong alkali acts chemically in the first instance upon the vegetable matter, and unites with some portion of it; but the remainder is thus left in a disorganized condition, and so made subject to the ordinary processes of decay and putrefaction, and these processes in their turn are known to prosper particularly in situations which are slightly alkaline.

Manifestly, the foregoing remark, if true of the compost heap, will be true also in some degree of any soil containing organic matter to which caustic lime is applied. To this cause are usually attributed the excellent effects produced by lime after green manurings in many localities, and when applied to new land, where the sod has recently been turned under, or to land so foul with weeds that a sort of green manuring is obtainable by ploughing it. It is perhaps this tendency to destroy organic matter which makes the too frequent use of lime pernicious. To it is probably due in part the old-world proverb, "Lime enriches the father, but beggars the son."

It must always be remembered, however, that, when the use of lime first became general in Europe, the farmers were prone to believe that it could be employed as a substitute for stable manure. Hence a tendency to abuse in using it. No doubt many a field has been reduced to the verge of sterility by applying lime until the entire store of available nitrogen and phosphoric acid and potash had been used up. All the evidence teaches that lime is no substitute for manure; it is a mere addition or reinforcement which may occasionally be employed with advantage.

Years ago, when lime was the only commercial fertilizer accessible to the farmer in the interior of Europe, he thought himself compelled to use it at every pinch; but now that many other kinds of fertilizers can be bought, the tendency to use lime injudiciously has been greatly lessened.

The corrosive power of lime explains the danger of allowing seeds or young plants to come in contact with too much lime. Davy found long ago that it was an easy matter to kill grass by watering it with lime-water.

Lime may decompose Minerals.

Another corrosive action of lime is seen in its power to hasten the disintegration of refractory silicates. Such action as this would usually be brought about much more readily by caustic lime than by gypsum, and there can be little doubt that the disintegrating action of lime upon feldspar and other minerals may sometimes be of considerable importance. It has been reported, indeed, that applications of lime have often been found to be specially efficacious on such clay soils as contain many fragments of broken but still undecomposed feldspar.

There are in fact many kinds of clays which are acted upon to no inconsiderable extent by lime. If a small quantity of such a clay be stirred into milk of lime, and the mixture be left to itself for a week or two, it will be found, on treating the mass with muriatic acid, that a good deal of the clay will dissolve, with separation of gelatinous silica, though, as is well known, clay by itself is not much acted upon by muriatic acid.

In the case now in question, the lime and clay seem to unite to form a small quantity of a hydrous silicate of alumina and lime, such as has been so often spoken of as useful to hold potash and ammonia in the soil. But during the formation of this compound, there must have been set free from the clay, or loosened up, as it were, within it, whatever of potash or ammonia the decomposed portion of the clay may have contained.

There are experiments by Stoeckhardt which show that caustic lime attacks, not only feldspar, but powdered quartz as well, and pure precipitated silicic acid, and that it combines with the silica so as to form a hydrated silicate of lime which is easily soluble in acids. It is known withal, from the examination of mortar from old buildings. that caustic lime does slowly act upon silicious sand to form small quantities of a hydrated silicate of lime readily soluble in acids. The same easily soluble silicate may be obtained directly by mixing lime-water with recently precipitated silicic acid. It is worth noticing, moreover, that Stoeckhardt's experiments were made upon minerals which had previously been leached with acid and with water until everything soluble had been removed from them.

Scientifically speaking, it would be possible, on the plan of these experiments, to establish compost heaps consisting solely of lime and clay, with the idea of loosening or "unlocking" some of the useful constituents of the clay. But it can hardly be supposed that the idea could ever be carried out with profit in actual practice.

Another point to be remembered is the fact, which has been illustrated repeatedly by laboratory experiments, that an admixture of lime salts or even of carbonate of lime with a soil increases the power of that soil to absorb and fix potash, soda, ammonia, and the like, from their solutions.

In view of the various modes of action of lime, as above set forth, it seems possible to understand that both the French and the German writers may be correct in their seemingly conflicting assertions; viz. by the first, that the best action of lime is seen on light, and by the last, on heavy land.

It is certainly true that lime may improve heavy clays by flocculating the finer, colloid portions of the clay, and so making the soil less pasty and sticky than it is naturally; and it is probably true also, that lime often does some good on such soils by corroding and disintegrating their constituents. On the other hand, lime may do good on some light, permeable soils, both by cementing their particles to a better capillary condition, somewhat as mortar might, and perhaps by charging the land with hydrous silicates. The action of lime to correct sourness, or to promote decay, may be more frequently important, perhaps, on heavy lands than on light; while upon light soils the influence of the lime to make the crops healthy, or even finally to promote nitrification, may be of more importance than it is on heavy soils.

Quicklime speedily changes to Carbonate in the Soil.

It is not to be supposed that, in the field, reactions due to the causticity of lime can go on for any very long period. Not only are the pores of the soil charged with carbonic acid, which would soon reduce the caustic lime to the condition of carbonate of lime, but a great deal of carbonic acid is produced by the action of the lime upon the organic matters of the soil. The action of the carbonate of lime, when formed, will not differ essentially from that of marl, or powdered limestone, such as will be described directly.

It is said to be a fact of practical experience, that plants vegetate somewhat more rapidly in good soil that has been limed, than upon that which has received no lime; that is to say, it is held that the time required for the crop to grow and ripen is somewhat shorter upon the limed land than upon that which is not limed.

Poor Soils are unfit for Liming.

One conclusion to which the foregoing discussion leads is, that lime is not a thing to be applied to really poor land. It can hardly by any possibility do good unless the soil is already fairly well charged with the constituents of plant-food. Its function is to alter and improve matters that are already in the soil, and to make them more easily available for crops, as well as to bring the soil into such condition that it can enable added fertilizers to be put to better use than they could have been without the liming. It is an adjunct to be used occasionally, but no proper substitute for manure.

Amount of Lime applied to Land.

The amount of lime applied to the acre varies widely in different countries, and according to the kind of soil. In general, it is used far less freely nowadays than it was formerly. Heavy clays can bear much more of it than light, sandy loams. Inasmuch as the chief action of lime is undoubtedly to improve the mechanical condition of the land, it is evident that the lime should not be applied in quantities too small to effect this purpose. It should be thought of and applied as an ameliorant in terms of tons, and not as a fertilizer to be used by pounds.

In England 4 tons of lime to the acre are esteemed to be sufficient for light lands, and for land that has been long under cultivation; or, instead of this quantity, more frequent dressings of 1 or 2 tons at a time may be used. For old sod-land that has just been ploughed, 6 tons of lime was the dose formerly recommended; and in those days quantities ranging all the way from 6 to 12 tons seem to have been usual applications, the larger amounts being applied in cases where the land had not previously been limed. Cold clay soils were limed more heavily (8 to 10 or 12 tons to the acre), and more frequently also (once in six years, or even oftener), than any others, for the reason that the lime makes such land work more kindly.

Latterly, smaller dressings at more frequent intervals have become customary in England. More than 5 or 6 tons to the acre are now seldom used there, even on strong land. Instead of applying 4 to 8 tons once in fifteen or nineteen years on land that had been previously limed, the rule is now to apply lime every six or eight years in quantities not larger than 1 or 2 tons to the acre.

In Germany lime used to be applied at the rate of 6 to 12 tons to the acre once in 7 or 8 years. In France the custom seems to always have been to use less lime, viz. 3 or 4 tons to the acre once in 7 or 8 years; and in Belgium the rule was to apply some 2½ tons to the acre once in 10 or 12 years.

It is held that deep soils require to be limed more heavily than those which are shallow. Practical men say that the reason why land requires to be limed anew after a longer or shorter interval depends primarily on the fact that the lime tends continually to sink deeper and deeper into the soil. Were it not for this peculiarity, they can see no reason why one good dose of lime should not serve for a century.

Carbonate of Lime.

A few words remain to be said about carbonate of lime, as such, though of course wherever caustic lime is applied to land it comes to act as carbonate of lime as soon as it has once been thoroughly neutralized with carbonic acid; and it may well be true that in many cases the good effects of liming are really due to the carbonate of lime which results from this speedy neutralization.

Reference has already been made, under Composts, to the fact that the lime carbonate favors the fermentation of humus and nitrification also. The experiment of Schulze, already cited, is of special interest as bearing upon this point. In repeated instances he charged pairs of glass cylinders standing in mercury, and full of atmospheric air, with equal quantities of loam that was rich in humus of rather sour character. But he mixed the loam of one cylinder with $\frac{1}{10}$ its weight of carbonate of lime, while to the other cylinder he made no addition. After the lapse of from 4 to 8 days he found habitually that all the free oxygen had disappeared from the air of the cylinder that contained the lime carbonate, and that this oxygen had been converted into carbonic acid by oxidation of the loam, while in the other cylinder not more than half the oxygen was consumed in the given space of time. Ordinarily the oxidation of the mere loam was more than four times slower than that of the limed loam.

Carbonate of Lime may prevent Puddling.

The importance of the lime carbonate as a means of hindering the puddling of clayey soils has already been mentioned under the head of Lime. It appears, indeed, that in very many instances it is really a solution of carbonate of lime in carbonic-acid water, i. e. the so-called bicarbonate of lime, which is the effective agent for coagulating the clay. The water of the Lake of Geneva offers a noteworthy illustration of the action now in question, for this water is particularly clear in spite of the great turbidity of the glacial streams that flow into the lake. All the suspended matters are coagulated and precipitated as soon as they mix with the lake water, which is charged with the lime carbonate.

In 10 litres of water taken from the Rhone at Geneva, at a point where it has the same composition as the lake water, Deville found 789 milligrams of carbonate of lime, 49 of carbonate of magnesia, 466 of sulphate of lime, and 63 of sulphate of magnesia; i. e. in one litre 63½ mg. of lime, and 4½ mg. of magnesia. Small quantities of alkali salts were present also.

Other things being equal, there is less risk that a soil which contains considerable quantities of lime carbonate will be puddled by rain than there would be if none of the carbonate were present. Even when the store of bicarbonate and other saline matters naturally present in the soil-water has been diluted or washed away by rain, new portions of it will speedily be formed to coagulate anew any particles of clay which may have been puddled.

Schloesing has suggested that, if soils could be conceived of that contained neither solutions of the lime carbonate nor of other saline matters in their pores, the earth would no longer have the power to clarify muddy liquids. On the contrary, the soils themselves would be changed to mud whenever rain-water fell upon them, and all brooks and rivers would be muddy, because the clayey and loamy parts of soils would slowly be washed away through them into the sea, until nothing but sand and gravel were left behind. Possibly such elutriation and straining of clay from sand may really have occurred to some extent in geological epochs anterior to the appearance of vegetation on the earth's surface; for when soils contained no humus, and particularly when the waters that washed the soils were warm, it may perhaps have happened that not enough carbonic acid for the rapid solution of lime and the effective coagulation of the clay was brought into contact with the soil.

Calcareous Soils are Fertile.

In some tracts of exceedingly fertile land in Germany it has been found that the soil contains 8 or 9% of carbonate of lime throughout the entire region; and the good effects of marl and leached ashes all over the world go to show that it is well to have a large store of carbonate of lime in the land. It has been noticed also by geologists, that, where limestone formations and deposits of clay meet and mingle, fertile soils are apt to occur. Doubtless many of the fertile calcareous soils now under cultivation were formed originally by the commingling of river mud and coral sand in just proportions at the bottom of the sea. Of course, in cases where the organisms which build the coral, or other living things, have been buried in the mud or clay, the final soil may contain a fair proportion of phosphates and other forms of plant-food beside carbonate of lime.

It is said to be commonly remarked in England that the clayey and loamy soils of that country are fertile only when they contain an appreciable quantity of lime. Where clay soils occur there on the edge of the chalk districts it is a common practice to "chalk" the clay. Chalk is carted upon the clay land at the rate of some 80 to 100 cubic yards to the acre, and left to disintegrate over winter, in little heaps 4 or 5 yards apart, which are spread in the spring.

The great fact, that limestone regions are fertile regions almost everywhere, does but reinforce the argument. When the farmers of New England have come to understand more clearly than they do now that the leached ashes they so much esteem are really little more than very finely powdered limestone, they will probably begin to use other forms of the lime carbonate more freely than they do now. There is, by the way, nothing of novelty in this assertion. Ruffin in his work "On Calcareous Manures," long ago wrote as follows: "Wood ashes, after being deprived of their potash, have calcareous earth and a small proportion of phosphate of lime as their only fertilizing ingredients; and both together do not commonly make more than there is of calcareous earth in the same bulk of good marl. Except for the proportion of phosphate of lime they contain, drawn ashes are simply artificial marl, more fit for immediate action by being finely divided, but weaker than our best beds of fossil shells."

Calcareous Sands and Shells.

A sand of carbonate of lime consisting of finely comminuted seashells, found in sheltered bays upon rocky coasts, is largely used as a fertilizer upon the coast of Ireland and the Channel coast of France, as well as in some parts of England. From the little ports on the Channel the French farmers transport this sand inland 20 or 30 miles in wagons, and in Cornwall it is carried to even greater distances by rail. It is said to be applied with special advantage to stiff clay soils. In France, besides being applied to clays, it is used with much benefit on marshy grass-lands at the rate of 10 or 12 tons to the acre.

Oyster-shell flour, such as was made in great quantities in Boston a few years ago, was as good, and probably better, than the shell sand. But there is small reason to believe that the powdered shells are any better than lime obtained from shells that have been burnt. In experiments made upon light land at the Bussey Institution it appeared that oyster-shell flour, that is to say fresh oyster-shells ground extremely fine, did not give quite so good crops as caustic lime that had been prepared by burning oyster-shells. Moreover, on analyzing sea-shells, it appears that the organic matter which they contain is wellnigh free from nitrogen. There is no evidence that this organic matter is of the least use as a manure. Hence there is no reason why the farmer should be at the expense, either of having the shells ground, or of carting the useless constituents which can be expelled by burning.

The cheapest way to obtain carbonate of lime in powder is to burn the original limestone, or sea-shells if they are to be had, and to slake the product with water. The slaking may be done in heaps covered with moistened earth, as has been described, and the fine powdery hydrate of lime spread directly upon the land, or the lime may be used in the compost heap; or the quicklime might be left to become air-slaked by exposure to the air, and the product be applied to the land instead of leached ashes. Air-slaked lime is sometimes spoken of as a hydrocarbonate of lime. It is in fact a particularly intimate mixture of the hydrate and the carbonate.

Of course it must happen, whenever freshly slaked lime is applied directly to the land, that it will act at first as caustic lime. Only after that action is finished will the influence of carbonate of lime be much felt. But manifestly by proceeding in this way the affair is complicated by the caustic lime which acts upon the land at one stage of the process, and no one can say just what carbonate of lime might have done if used by itself. It is not impossible that cases may occur where the action of the caustic lime upon the soil would be detrimental; and it is to be noted that, in such event, the difficulty would only be partially overcome by allowing the quicklime to slake in the air.

There is always one great advantage to be credited to quicklime, in that the cost of transporting it will be decidedly less than that of transporting powdered limestone. The atomic weights of calcium, carbon, and oxygen are respectively 40, 12, and 16; and the molecular weight of carbonate of lime ($CaCO_3$) is 100. But there are 44 lb. of carbonic acid (CO_2) in that amount of pure carbonate of lime, that is to say, almost one half the weight of the material; and by expelling this carbonic acid at the quarry, there will be just thus much less of dead weight to be transported to the farm.

The argument as previously stated means merely, that by applying powdered limestone or sea-shells the experimenter is in so far master of his position. He will know precisely what he is doing, and be able to judge from the crop whether or not the lime carbonate has done any good. But when the carbonate has been obtained as a secondary product by starting with quicklime, it can never be known with certainty whether the observed effects should be attributed to caustic lime or to the carbonate.

Use of Leached Ashes.

It is not impossible, when the modes of action of lime compounds come to be understood more clearly than they are now, that only carbonate of lime will be applied to some kinds of soils, and the use of quicklime be restricted to special varieties of land and to the compost heap. This conclusion is foreshadowed by the extended use that is made even now of leached ashes in many districts. In some parts of Rhode Island, Connecticut, Vermont, and Massachusetts, for example, leached ashes have long been highly esteemed, and they continue to be used in these localities very freely, even when the cost of the material is high. As much as 18 or 20 cents the bushel of 55 lb. is said to be paid for Canadian leached ashes in Connecticut. Leached ashes are always more or less moist, and may be estimated to contain 35% of water on the average, as received by consumers hereabouts. Nearly half of the moist material is carbonate of lime in the condition of a fine, soft powder. There are 3 or 4% of magnesia also, beside clay, sand, charcoal, and other impurities. Such ashes rarely contain as much as 1% of potash, or more than a per cent and a third of phosphoric acid. If the carbonic acid be classed as inert matter, together with the sand and charcoal, it will appear that scarcely more than one third the weight of leached ashes can be regarded as possessing any fertilizing value whatsoever.

Factitious Leached Ashes.

Professor Johnson has suggested that leached ashes might readily be imitated by mixing together 30 lb. of fresh-burned shell lime,[1] 8 lb. of kainit, and 10 lb. of fine bone-meal. These materials would supply 28 lb. of lime, 2.8 of phosphoric acid, 1.0 of potash, and 0.7 of magnesia; and, with the exception of magnesia, which is rarely lacking in soils, would probably be equal to 100 lb. of leached ashes, as used for fertilizing purposes. He urges that, in many localities, such a mixture might be economically substituted for leached ashes; and that, still better, such of its components as experience might show to be useful could be used to greater advantage than leached ashes themselves.

It is not improbable that the soils on which leached ashes do their best service are specially fit for nitrification, and that this process is promoted by the lime carbonate. In this view of the matter, leached ashes would be of little use on soils not rich enough in organic remains to admit of ready nitrification.

Beside the direct action of carbonate of lime in feeding the plant and reacting upon the various matters which occur with it in the soil-water, it has a distinct though feeble power of decomposing organic matters, something as an alkali would. There is nothing very extraordinary in this, for, as is well known, the solution of carbonate of lime in carbonic-acid water has a decided alkaline reaction; and, as the experiments of Johnson have shown, the action of carbonate of lime on peat is real though feeble.

Carbonate of Lime a Regulator.

The presence of a quantity of carbonate of lime in a soil may sometimes be useful as a safeguard against, or as an addition to, saline fertilizers. Thus, when chloride of potassium, sulphate of potash, and common salt are applied to land that contains carbonate of lime, the salts are slowly decomposed, with formation of carbonate of potash, or carbonate of soda, as the case may be, and these alkaline compounds have usually a better fertilizing action than the chlorides and sulphates whence they came. In this case the carbonate of lime acts as a regulator, as it were, to keep the land at its best; and so it is with regard to nitrification, as has been said.

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[1] Perhaps it would be well to slake the lime, and then expose it to the air in a barn cellar, with occasional stirrings, before adding the other ingredients.

Marls.

In connection with lime compounds marls should be considered. The word "marl" is a somewhat vague term, applied to mixtures of calcareous earth and various proportions of clay, or loam, or sand. There are marls containing no more than 5% of carbonate of lime, and others that carry 50 or 80% of the carbonate.

Shell marls, so called, consist of deposits of clay and silt, admixed with small shells, that are found beneath the surface soil of swamps, and sometimes at the bottoms of ponds. They must not be confounded with the diatomaceous earth (sometimes of pure white color) which is often found in similar situations, and which consists of innumerable siliceous shells of microscopic organisms. Occasionally, shell marls contain very large proportions of carbonate of lime. The heaps of oyster-shells, or of shells of sea or fresh-water clams, found in many places near the sea or on the borders of ponds and rivers where Indians formerly congregated, are in no sense to be regarded as marl. For the farmer, these shell heaps are simply stores of limestone fit to be burned to lime when the conditions are favorable for this enterprise.

Generally speaking, it is only the carbonate of lime in a marl that gives it its fertilizing power, though there are some rare varieties which contain appreciable quantities, not only of phosphoric acid and potash, but of organic matters rich in nitrogen. The good repute in which marls are held depends upon the fact that they are often found far inland in the hearts of agricultural regions, and may be readily applied to the neighboring land at no great cost for transportation. Unlike lime, they can rarely if ever do any harm, for there is nothing caustic or hurtful in them. Moreover, they may be, and are, applied in such large quantities as to alter the texture of the soil, and to serve as true "amendments."

A light soil dressed with seventy or eighty thousand pounds of clayey or loamy marl to the acre will be made sensibly heavier, and so, conversely, of a sandy marl applied to clay. The benefit of a thorough dressing with marl is said to be felt during ten or twelve years, though the effect is very variable, according to the character of the marl and of the soil.

It needs to be borne in mind that the mechanical condition of a marl has much to do with its value. Just as coarsely crushed bones are worth far less to the farmer than bone-meal, so a rough, lumpy marl will have less value, other things being equal, than one whose particles are fine. It follows, of course, that mere chemical analysis of a marl is not sufficient to determine its value.

Marls are commonly classed, according to their mechanical condition or consistence, as stone marl, shell marl, earthy marl, or slaty marl. A striking peculiarity of the really good marls is their capacity of falling to powder under the influence of the weather after they have been spread upon a field. This phenomenon depends upon the unlike behavior towards water of the clay, the sand, and the calcareous earth which the marl contains. The clay swells on being wetted by rain, while the sand and the lime carbonate do not. When dry weather sets in, the moist clay shrinks in upon itself, while the sand and the lime compound remain unchanged. Hence, by alternate wettings and dryings, the coherence of the marl is destroyed, and the original lumps of it gradually crumble to powder. In winter also the crumbling process is hastened, when the weather occasions alternate freezing and thawing.

The use of old mortar, or plastering taken from buildings that have been burned or otherwise demolished, though hardly analogous to marling properly so called, may in general be regarded merely as an application of coarse carbonate of lime, though there is often some gypsum in the mixture, more or less caustic lime, and occasionally a little nitrate of lime.

Recapitulation.

To recapitulate, and the question now is of lime proper: —

Lime may act to alter the capillary condition of the soil, both by coating the earth, as was explained, and by flocculating the colloid clay in it.

It may act on hydrous silicates in the soil, to push out from them potash, or the like.

It may decompose the inert nitrogen compounds in vegetable mould, and may even do good by merely disorganizing vegetable remains.

It may neutralize undue acidity, whether caused by an excess of humic acids, or by the presence of ferrous sulphate.

It may destroy insects and worms, and some hurtful fungi; though the presence of carbonate of lime in the soil is important for nitrification.

It disintegrates rocks and minerals.

The presence of it in the soil often increases the "absorptive power" of the soil; that is to say, the power of fixing and holding potash, etc.

CHAPTER X.

SODIUM COMPOUNDS.

Of sodium compounds, considered as fertilizing agents, comparatively little need be said. Methodical experiments have shown that sodium is apparently not essential to the life of agricultural plants. Crops can grow perfectly well without it. Or, at the most, they need so small a trace of soda that enough can always be obtained from the supplies to be found in the soil, or even in the air. The soda usually found in the ashes of plants is accidental, and non-essential. The old notion that soda could replace potash in the plant has been disproved.

Animals, to be sure, need salt, or some other sodium compound, in order that they may live; and, ordinarily, they obtain the chief part of their supply of soda from plants. But these considerations have little or no bearing on the question of agriculture. Domestic animals might always be supplied with soda by administering to them salt, or sulphate of soda, directly; and it would be economically absurd to send them the soda by the roundabout way of the plant. And yet, in spite of all this, common salt is often found to do good service as a manure.

Mode of Action of Common Salt.

The explanation of this fact seems to be that the salt acts indirectly. It effects the decomposition of substances already present in the soil, and sets free from them some things which are needed by plants. It is somewhat with salt as it is with gypsum, except that, while gypsum pushes out potash with especial ease, as well as magnesia and ammonia, from the hydrous double silicates, common salt displaces lime first of all, then magnesia, and potash (as well as some phosphoric acid) only to a subordinate extent. The discovery, however, even of thus much, viz. that salt acts indirectly to dissolve matters that are already in the soil, has served to clear up one of the most obscure points in the chemistry of agriculture.

Until a comparatively recent period it was impossible to comprehend the conflicting statements about the use of common salt that were published every day. One farmer found it a valuable manure;

another was led to regard it as a poison sure to destroy his crops, while a large number of observers, perhaps the majority, could not perceive that they derived either benefit or damage from its use. On the whole, the verdict of most practical men appears to have been rather unfriendly to the use of salt. It is now known, however, that, with many soils, lime, magnesia, and potash can be given to the crop by applying common salt, or any other soluble sodium compound, to the land. There is a curious old experiment of Professor Wolff, which bears upon this point. Wolff grew a quantity of buckwheat upon a field, one half of which was manured heavily with common salt, while the other half was left unmanured. On analyzing the ashes of the buckwheat straw, he found that the portion of the crop which had received the salt contained less soda, but more potash, than the other.

An application of common salt to the land might thus exert a decided fertilizing action, by merely pushing out lime and potash from the surface soil, and sending them down to where the roots of the crop are growing. The probabilities are, however, that this elimination of potash can usually be effected more cheaply by means of lime compounds than by means of sodium salts; and if a sodium salt were used for this purpose, the nitrate, which is a valuable manure of itself, because of the nitrogen contained in it, had better be chosen.

Several chemists have studied the disintegrating or solvent action of common salt, and of a variety of other saline substances, upon soils, and rocks, and minerals, not to speak of multifarious experiments of analogous character relating to fixing power. Some of the most noteworthy of these trials are those of Dietrich (Hoffmann's Jahresbericht, I. 29 and V. 12) and of Beyer (Ibid., XIII. 22).

Use of Salt to check rank Growth.

Salt is sometimes used to check vegetation. That is to say, it is employed not infrequently in England to hinder the growth of grain crops, or rather to prevent the stalks from becoming too rank on rich soils, or on soils too highly charged with nitrogenous manures. It was a not uncommon practice formerly to mix the true Peruvian guano with salt, and the English farmers still use salt to hinder their grain crops from running to straw in wet seasons.

The physiological action of salt in this case is not well understood. Perhaps the salt kills the nitric ferment or some other organism that works to make the soil nitrogen active, or, at the least, hinders its development. Possibly the effect of the salt may be due to a general weakening of the plant. As everybody knows, large doses of salt will kill most plants. Perhaps smaller doses may check growth by giving the plants an illness from which they slowly recover.

It has often been noticed, even in localities where salt has been found to do good service as a fertilizing agent when ploughed under, that top-dressings of it seldom increase the crops, and that they are often distinctly hurtful. One case has been reported where 9 cwt. of salt strewn upon a Saxon acre had no visible action upon either wheat or rye, while it killed young clover. In general, it is agreed that care must be taken to use salt sparingly, and to apply it at appropriate seasons, as when neither seeds, nor sprouts, nor young plants are at hand to be injured. Instances are on record where more than 3 cwt. to the Saxon acre diminished the beet crop, and more than 4½ cwt. diminished the yield of potatoes. In some places 1 or 2 cwt. to the Saxon acre, applied to rye, gave the best results, while in other situations the best rye crop was got with 6 cwt. In this instance, an application of 9 cwt. diminished the crop, and 12 cwt. lessened it still more. A barrel of salt to the acre, for wheat, is one English formula.

Possibly it is the chlorine in the salt which acts to restrain the growth of wheat, rather than the sodium. If this be so, it might be better to use chloride of potassium (Stassfurt muriate) rather than common salt; or possibly a light dressing of chloride of magnesium, which would be cheaper even than salt, might serve the purpose. It would be interesting to study the comparative action of common salt and of chloride of potassium upon some of the over-rich bottom lands at the West. On the so-called American Bottom in Illinois, for example, the growth of stalks and straw is said to be enormous in proportion to the yield of grain. Corn-stalks grow ten or twelve feet high, and are sometimes five inches in circumference, while at about the height of a man's head they bear a single ear of corn. For all the rank growth of stalks, the harvest is hardly 50 bushels of corn, or 25 bushels of wheat, to the acre. It would be an interesting experiment to try whether salt, or any other chlorine compound, would in this case bring the stalk production into fit relations with a proper crop of grain.

It is not in the least unlikely that salt may exert other physiological effects than those just now suggested, for Nessler has noticed that tobacco grown on land manured with salt had tougher and more flexible leaves than that grown on adjacent unmanured land. So too, hemp that had been lightly manured with salt yielded a larger amount of useful fibre, and a fibre of superior quality, than was got either from unmanured land or from land fertilized with sulphate of ammonia.

It has often been noticed, moreover, that dressings of salt, and even of chloride of potassium, tend to make potatoes waxy rather than mealy. Stoeckhardt has in fact shown, by an elaborate comparison of numerous experiments, in which the action of salt could be contrasted with that of other fertilizers, or with that of unmanured land, that, as a general rule, the percentage of starch in potatoes is diminished when the land has been dressed with chloride of sodium, either by itself, or as an addition to other fertilizers. Even the yield of tubers is apt to be diminished by the presence of salt in the soil.

Salt flocculates Colloid Clay.

There is another effect producible by salt, which may perhaps sometimes explain the utility of employing it upon clayey soils; viz. its power of making fine particles of clay cohere, as seen when the suspended matters in turbid river-water, or in mud-puddle liquor, are made to subside by additions of salt. That such action may occur is seen in Holland, where it has been supposed to produce a part of the injury that results when clayey polders are overflowed with sea-water. But it is not improbable that this very action may be beneficial in some cases, when the quantity of salt applied to the land is not too large.

As has been explained under the head of Lime, common salt and other saline solutions have a considerable power to flocculate fine earth, or any minute particles that are suspended in water, much as lime does. For example, when the Mississippi water flows into the saline water of the Gulf of Mexico, much of the matter that was held suspended in the river-water is flocculated at once, so that it can subside. Such action as this is one prime cause of the formation of deltas, for the flocculation of fine mud by salt is common to all rivers that reach the sea.

A curious instance of this phenomenon was encountered at Calcutta on establishing filtering beds of sand to purify the Hoogly water. It was found that, during the rainy season, the fine mud in the water penetrated very deeply into the filters, and rapidly choked them. In the dry season this did not happen, for the suspended matters were then arrested near the upper surface of the sand. The explanation is, that, during the rainy season, the water contains much less saline matter than in the dry season. And the trouble was remedied by adding alum and salts of iron. Conversely, where the waves of Lake Erie beat against the banks of clay upon its northern shore, the water is said to be discolored for miles out into the lake, manifestly because of the absence of saline matters to flocculate the colloid clay.

Flocculation by other Saline Matters.

What is true of salt in this respect is likewise true of most of the saline matters that occur naturally in arable soils (notably of bicarbonate of lime, as has been said); and it is known that these saline matters, in spite of the extreme dilution in which their solutions occur, do actually exert a highly important influence to maintain soils in good tilth. Schloesing has suggested the following experiment, as illustrating this point. A quantity of moist loam, having been crumbled between the fingers to a loose condition, is shaken into a cylinder, at the bottom of which fragments of glass covered with coarse sand have been placed. On moistening the loam with distilled water, drop by drop, a solution of the saline matters which the soil contained will be pushed downward beneath the layer of pure water, which has the upper hand, and the uppermost layers of loam will soon be left in contact with pure water, with which they finally form a mass of dough; i. e. when all the saline matters have been removed from the soil, it passes into the condition of pasty mud. Meanwhile the lower layers of the soil, although fully moistened and subjected to heavier pressure than the upper layers, exhibit no such change as to their mechanical condition, for they are still in contact with saline matters that hinder their particles from puddling.

On repeating this experiment with ordinary well-water, instead of distilled water, all the other conditions being as before, Schloesing obtained no mud at the surface of the earth. He explains his results as follows. In the fine earth, which we call loam, clay often acts as a kind of cement to hold particles of sand together. The clay gives coherence to the particles of soil, and keeps them from falling to mere dust. But this binding power of the clay is effective only so long as there is enough saline matter present to keep the clay in a coagulated condition. Whenever, by washing with pure water, the coagulating agents are removed, the clay loses more or less completely this kind of binding power, the friability of the earth disappears, and mud is formed.

Schloesing admits that not every kind of earth is suitable for the foregoing experiment, for in some soils many of the particles or granules are held together by other agencies than clay, and such soils are not easily puddled. Many of them will withstand the action of distilled water, as above applied. But it is still true that a large number of loams will behave in the manner indicated, and such soils are liable to be puddled at the surface when acted upon by rain, which is water that has been distilled naturally.

There are, however, noteworthy differences between the exaggerated conditions of the experiment and those to which soils are actually subjected in the fields. For although in the experiment the water is added very slowly, it may still happen that as much of it may be applied in a few hours as would amount to a layer ten or fifteen inches deep. But this would represent an enormous rainfall, such as is wholly unusual; hence the washing out of the saline matters must be more complete in the experiment than in the field. On the other hand, the beating action of rain, which must greatly promote puddling in the field, has comparatively little influence in the laboratory experiment. In the field, moreover, the rain-water, coming in showers and in comparatively small quantities, would often be able to dissolve enough lime from the soil (chiefly as bicarbonate) to hinder the flocculation. In the case of very heavy rains, it may happen also that the soil will be so thoroughly puddled at the surface, that is to say, it will become covered with mud that is so difficultly permeable, that not enough water can percolate downward to wash out the saline matters from the layers of soil next below, so that the tilth of the soil will not be much impaired excepting at the very surface.

To the presence in soils of the natural saline matters, Schloesing attributes the power of the soil to clarify turbid liquids. Were it not for the saline matters, he says, not clear sparkling water, but turbid and muddy water, would flow from field drains and springs, and be drawn from wells. In a similar spirit, Schulze argued that the soluble constituents of manures must often exert a considerable influence upon the texture of soils.

Not only do the saline matters in the soil exert an influence to preserve the mechanical coherence of the particles of earth, but it is plain, from the observations of Knop (page 477 of Vol. I.), that the chemical condition of the soil undergoes marked changes whenever the saline matters are washed out from it.

Sodium Compounds in the Air.

As has been said, every soil contains more or less sodium, which has been derived from the disintegration of silicates, or been brought down by rain from the air. The air everywhere contains minute traces of common salt, for as the winds pass over the sea they take up mechanically, as if it were so much dust, more or less of the fine spray which is blown from the tops of the waves. Some of the salt thus lifted is carried everywhere, even to the lands most remote from the ocean. More of this salt from the spray is, of course, deposited upon land near the seaboard than upon that farther inland. In the immediate vicinity of Boston there is so much salt in the soil, and in the plants which grow upon it, that there is seldom, if ever, any need of giving salt to pastured cattle. Hereabouts the animals will hardly eat any of it if it is offered to them, while a hundred miles inland stock kept in pastures will eat salt voraciously, and will not prosper unless occasionally fed with it. At the heart of the continent, wild animals used to travel many miles to the salt licks.

There are cheap kinds of salt that are sold purposely to be used as fertilizers. It is said that they should not be applied in larger quantities than at the rate of 300 to 600 lb. to the English acre.

In the vicinity of Boston several market gardeners are said to find their advantage in pumping brackish water from the tidal rivers for irrigating cabbages, cauliflowers, tomatoes, celery,[1] horse-radish, and onions. For these particular crops the saline water is preferred to fresh water. It is often applied so freely, that the ground on drying becomes white with salt. Mature plants of the kinds above mentioned are not injured; but it is said that the salt water would kill even these plants if it were applied to them when young. Melons are said to be killed by it at all times.

The power of some kinds of plants to resist the injurious action of salt is noteworthy. Asparagus is a case in point. Many people use salt to manure their asparagus beds, but it is commonly thought nowadays that the salt acts in this case chiefly to destroy weeds. The fact that the cocoa-nut tree can bear salt water has often been noticed. As long ago as 1688, Dampier wrote as follows of an island near Sumatra: "This island, Triste, is not a mile round, and so low that the tide flows clear over it. It is of a sandy soil, and full of cocoa-nut trees. The nuts are but small; yet sweet enough, full, and more ponderous than I ever felt any of that bigness, notwithstanding that every spring tide the salt water goes clear over the island."

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[1] Compare Bulletin of the Bussey Institution, II. 370.

Salt as a Germicide.

It is still an open question as to how much good, if any, is to be attributed to salt as a means of destroying fungi and insects when used in such comparatively small quantities as are commonly applied to the land. It is not impossible that there may be something in the idea, since it is a well-known fact that strong brine will destroy many fungi and spores of fungi that are injurious to plants. The following statement as to the usefulness of salt was made a few years since by one of the most successful planters at the South.

"I have used salt," he says, "for fifteen or more years. I find it essential to success on all lands like mine, and most of the cotton lands are like mine. 300 lb. of salt and 200 lb. of plaster are almost a total preventive of rust, which is one of the worst enemies the planter has to contend with. Salt makes cotton bear longer in the season, and stand drought better; it increases the quantity, and improves the quality. It acts equally well on corn, oats, and other grains, and it toughens wheat straw so that there is less waste from ears breaking off when the crop is cut."

But here again chloride of potassium might perhaps do better service than chloride of sodium.

Common salt is said to have been used at one time to a considerable extent in Switzerland as an addition to the liquid that drains out of the dung-heaps into pits which are made to receive it. The mode of action of the salt in this case has not been explained, but good effects are said to result in practice from its use. Possibly it acts as a preservative by hindering fungi from acting on the manure. Probably some of the Stassfurt products would be better for this purpose than salt.

Action of Salt and Lime in Soils.

The action of a mixture of salt and lime in compost heaps has already been explained as due to the formation of a small quantity of caustic soda, which causes the peat or other organic matter to ferment. But, as has been said before, chloride of potassium would perhaps be better than chloride of sodium to use with the lime;

and it would probably be more advantageous to buy caustic soda outright, or, better still, to buy caustic potash, which is equally strong with soda as an alkali, and is a true manure into the bargain.

It is to be noted, however, that this power of salt and lime to react upon one another in presence of porous bodies, with formation of an easily soluble alkali, such as soda or carbonate of soda, may explain a certain class of cases in which salt has proved efficacious as manure. In this way, when salt is applied to a limestone soil, there may really be given to the land a dressing of carbonate of soda, and of the efficacy of this substance to promote the decay of humus and the disintegration as well as binding of the soil there can be no question.

Indeed, it is hard to escape the conviction that there must be soils the fertility of which is promoted in this way. For it is seen in alkali deserts that the reaction between salt and limestone does really occur in nature; the only trouble in this special case being that the reaction is too strong for the purposes of agriculture. So much of the soluble alkali has been formed in these cases that plants, or, at the least, the texture of the soil, have been destroyed by it. But inasmuch as it is known that small quantities of the alkaline soda carbonate may be beneficial both to plants and to some soils, it seems plain that this substance must sometimes conduce to fertility, even when it has been formed naturally. It is difficult not to believe that there are somewhere in the world localities where the reaction between salt and limestone may occur habitually in the proper degree. One merit of the soda carbonate is, that it can dissolve to an appreciable extent phosphate of iron such as is formed in the soil.

CHAPTER XI.

THEORY OF THE ROTATION OF CROPS.

BESIDE tillage and the use of fertilizers, there are various other methods of increasing the yield of crops; and one of the most important of these methods is the growing of different kinds of plants from one year to another upon a given field, instead of taking one and the same kind of crop continually from the land, year after year.

When this "rotation of crops" was practised systematically and strenuously, so to say, according to well-established rules and customs, as was done formerly in many parts of Europe, the idea was to divide the farm into as many parts, or divisions, as there were kinds of crops to be grown, and to raise a different crop upon each division every year. Suppose, for example, the rotation were one of five years, the farm would be divided into five "shifts," as the English term is, and the crop of the present year — wheat, for example — would be grown upon division No. 1; next year it would be grown upon division No. 2, and so on; while the next crop in the series, whatever it might be, would follow the wheat. That is to say, this next crop would be on division No. 5 this year, and on No. 1 next year. On the sixth year wheat would get back to division No. 1.

Practically, it should be said, the entire farm, if it were at all large, was seldom thus divided in gross for the purposes of rotation. On the contrary, the farm was first divided, according to the lay of the land and the character of the soil, into several great sections, and each of these sections was divided in its turn into the separate fields, or shifts, just spoken of. By proceeding in this way, it was possible to distribute the crops to better advantage, and to have each of them represented every year upon different parts of the farm, so that, no matter what kind of weather might be vouchsafed, each crop would have opportunity to succeed somewhere upon the farm.

Every year just so many acres are laid down to wheat, to rye, to flax, to clover, or what not; and, taking one year with another, tolerably definite and determinate yields are to be expected from each of the crops, so that a constant number of cattle may always be kept, just so much manure will be made, just so many products sold, and just so much income be counted upon. All this tends, of course, to fixed and constant work and results, not to say to rigidity of method and action.

We have now to inquire why it was that the farmers took all this trouble; for, assuredly, it would seem to be more natural for them not to have tied themselves up in such complex arrangements, but to have grown their crops where they pleased and when they pleased. Several of the more important facts, upon which the theory of the whole subject of rotation may be said to depend, may be enunciated as follows. Some kinds of plants require much less food than others. Or, rather, they can prosper when neither table nor larder is spread or filled, i. e. in situations where very little food is placed at their immediate disposal. Look at the cactuses of the desert, for example, and at the beach-grass that grows on drifting sand-dunes, and at the pitch-pine trees of the sand-hills of New England.

Good instances of plants whose habits are utterly unlike those of these hardy pioneers are to be seen in various ornamental trees which have been brought to this country from Europe, such as the horse-chestnut and the sycamore-maple (Acer pseudo-platanus). Both these trees thrive in cultivation in the vicinity of Boston, and they seed freely; and when the seeds happen to fall upon rich land they germinate readily enough, and grow until the saplings are cut off by the gardener's hoe or the mower's scythe. Neither of these trees has become naturalized to the locality, although the horse-chestnut at least has been a favorite tree here during many generations. To all appearance, the trouble is that these particular trees require rich land when young, and that they cannot get started in life on poor soils, or in waste and neglected places.

Then, again, different kinds of plants differ widely as to their power of drawing food from one and the same soil. Compare, for example, the desert plants just spoken of with the ordinary plants of cultivation; or, among the agricultural plants, contrast buckwheat, rye, oats, or lupines, which will grow on extremely poor soils, with the crops that require richer feeding. Rye and buckwheat can be grown with profit, as may be seen every year in New England and in Northern New York, on soils where most other crops would starve.

Conversely, there are crops, such as wheat and barley, that must not be fed too richly, lest they run to straw and produce no adequate yield of grain. Years ago, when wheat was commonly grown in Europe on a clean bare fallow, to which a certain amount of manure was applied, it seemed to the men who practised this system of husbandry that a limit had been set to the amount of wheat that could be grown on an acre of land. They found themselves unable to force the wheat to yield more than a certain tolerably definite quantity of grain, for the moment they applied to the land any more than the usual quantity of dung, their wheat was apt to fail, because the plants ran to leaf and lodged before coming to maturity.

One of the most important improvements in the practice of rotation has depended on the discovery that it is only when manure is applied directly to the wheat crop that it causes the trouble now in question. In point of fact, it was found out long ago that much better crops of wheat than were previously obtained can be grown by applying an abundance of manure to certain preparatory crops, such as horse-beans and clover, which do not suffer from very heavy dressings of dung, and which leave the land in excellent condition, both physically and chemically speaking, for the growth of wheat.

It is not easy to conceive of the causes of differences, such as the foregoing, in the power of plants to procure food from a given store, unless they are in some way connected with differences in the very structure of the plants themselves. It is plain, at all events, that, in studying rotations, the peculiar characters and habits of growth of the several crops need to be kept in view as carefully as the chemical constituents of the soil, or of the manure that is put upon it, for the power of each particular crop to assimilate materials from the soil is really the prime consideration.

As is manifestly the case with the wheat plants just mentioned in their relations with dung, it may be said in general that the success of a given crop may depend largely upon the quality of the chemical constituents of a soil, rather than upon their kind or their quantity. It is conceivable, for example, that wheat may feed better upon one combination of nitrogen, or of phosphoric acid, or of potash, than upon another. Possibly it might do better with ammonium salts than with nitrates; better with diphosphate of lime than with triphosphate, or with the double silicates that contain potash than with the double humates. But by long-continued cultivation of the wheat (or of any other one crop) there may be established, by mere exclusion as it were, a vicious set of combinations in the land. Perhaps the so-called "clover-sick" land may be a case in point.

It need hardly be said, moreover, that different soils differ widely as to the amount of assimilable plant-food contained in them, according as manure has or has not been recently applied; or that, from the different styles of roots of different plants, different methods of feeding must result. It is a popular impression that some plants, like lucern, and several other kinds of clover, throw out such large and long and numerous roots that they are able to extract nourishment from a large bulk of soil. We may contrast, for example, the very different habit of growth of root crops, such as turnips, beets, carrots, and parsnips, and that of the grain crops; or we may look at some wild plants, like the beach-pea, that has enormously long roots, with which it searches for food far and wide among the stones at the heads of beaches; or like the horse-tail or scouring-rush of wet sandy places, which has, as the farmers say, no end of roots. So it is probably with many of the weeds that grow in what botanists call waste places.

Structure of Plant Roots.

The study of the structure of the roots of plants is extremely important, but so difficult, or rather so tedious, that comparatively few irreproachable experiments concerning it appear to have been made hitherto. It has been clearly made out, however, that, when the condition of the soil permits their perfect development, roots grow according to definite architectural plans, which are just as symmetrical and characteristic for each particular kind of plant as the forms which are assumed by the plants above ground in respect to the arrangements of their stems, branches, twigs, and leaves. (Hellriegel.)

It has been found, for instance, on comparing the network of roots of barley, buckwheat, and clover plants of similar age, and grown under conditions favorable for perfection, that the three objects are as different, as well characterized, and as easily distinguishable one from another, as the plants themselves. Plants as nearly related as peas, lupines, and horse-beans have systems of roots which are very unlike, and the same remark is doubtless true of most other plants. All this on the supposition that the roots are growing in a light soil, of homogeneous character both as to tilth and fertility.

The very first roots that form are thrown out without any reference to the amount of plant-food in the soil. They will grow as well, or better, in moistened sand as in loam. Indeed, it is noticed by gardeners that more roots seem to be formed at the start in sterile soils than in soils which are fertile. It is only after the roots have attained a certain development that they are apt to linger in the vicinity of any special store of food which they happen to meet in the soil, and to grow there more freely than in the comparatively barren earth around it.

It must not be forgotten, however, that the power of roots to adapt themselves to circumstances is very considerable, or that they do habitually, and as a rule, develop most freely in those directions where there is least resistance to their progress; i. e. where the soil is open and mellow, and in spots where there are abundant supplies of food, and a sufficiency of moisture. Thus it happens that the roots of any given plant may sometimes be found to have grown near the surface of the soil, and at other times at lower depths. Indeed, it may be said of actual field practice, that, in most instances, the manner of the development of the roots of a crop depends more upon the condition of the soil than on any inherent peculiarity of the crop.

One prime difference in the structure of roots depends upon the fact, that, while many kinds of plants send down vertically a strong tap-root, with which the body of rootlets is more or less intimately connected, other kinds have no such central axis, but send out at once several or many branching roots, any one of which is as good as either of the others. Upon these main stems, as it were, the subordinate roots are arranged in regular rectilinear rows, which manifestly stand in some kind of relation with the twigs and leaves above ground. Indeed, the length and magnitude of the roots of any plant must depend ultimately, in any given case, on the vigor and general prosperity of the plant. Other things being equal, large, well-developed plants will have more abundant roots than smaller or less satisfactory specimens.

The number of rows or series of subordinate roots, and their positions upon the main roots, are different in each kind of plant, and form a characteristic feature or peculiarity of the plant. Some plants throw out lateral roots with great regularity, and at small distances from one another; while in other kinds of plants there are wide interspaces, and the arrangement is irregular.

In some plants the subordinate roots grow with equal degrees of rapidity, so that the oldest are always the longest, and the soonest beset with rootlets; while with other plants the growth of particular roots is much more rapid than that of others. Sometimes these free-growing roots are always the uppermost or oldest, while in other plants it is the lower and younger roots which exhibit this peculiarity.

According to Hellriegel, it is a mistake to classify plants, as has sometimes been done, as those which are deep-rooted or shallow-rooted according as they have tap-roots or not. Grain plants, for example, have no tap-roots. They send out at once, when vigorous, as many as 20 or 30 branching roots, which drive downward, often to great depths, when the conditions are favorable. From these main roots other roots of varying degrees of magnitude are thrown out, which are hardly any shorter than the main roots, though finer.

Depth to which Roots of Grain penetrate.

Many farmers have put upon record their astonishment on noticing the great depths to which grain roots penetrate. Mr. Chamberlain, formerly of Ohio, having occasion to lay some three miles of tile drain three feet deep in a field of hard, stiff clay, upon which wheat had been grown that year and the year before, noticed that every spadeful of earth thrown out of the trenches, even that from the bottom course, was full of fine wheat roots, both live roots from that year's crop and half-decayed roots from the plants of the previous year. How much deeper than 3½ feet the roots went, Mr. Chamberlain did not try to determine. At the time of these observations the surface of the land was very dry. There had been no rain for a month; but at a depth of three feet the soil was fairly moist, and even at two feet there was a good supply of capillary dampness.

It is plain from all this that there is no cause for surprise that wheat should habitually stand drought well, especially on clayey loam.

In 1851, Schubart, a German farmer, made measurements of various roots which he washed out from the soil of fields where the crops were growing. He found that the roots of wheat sown late in September extended to the depth of 7 feet Rhenish in a subsoil composed of sandy loam, while in a somewhat stiffer subsoil they went no deeper than 6 feet. In other trials, wheat sown at the end of September had roots 3 ft. 2 in. long at the end of April, and that sown at the end of October had roots 2 ft. 11 in. long. Six weeks later, i. e. at the middle of June, the roots of the early sown wheat were 3 ft. 11 in., and those of the late sown, 3 ft. 7½ in. The soils in these cases were stiff loams.

Rye sown at the end of August, in deep loam, had roots 3 to 4 feet long in November of the same year, although the leaves of the plants had only reached a height of about one foot. At the same time rye that had been sown four weeks later had roots from

1¾ to 2¼ feet long, and leaves 4 to 6 inches high. Rye sown at the middle of September, on heavy land, had roots 3 ft. 9 in. long at the end of the following April, and they were only half an inch longer at the middle of June.

Rapid Development of Young Roots.

The rapidity with which the roots of the young grain plants were developed in these instances illustrates a very general fact, which is true of most agricultural plants, viz. that in early youth, after a few leaves have been put forth, plants devote themselves specially to the development of a powerful system of roots before any very extensive growth of leaves or stem occurs above ground. The shooting of grain, for example, does not take place until after many roots have been developed.

The fact now in question has been proved, not only by measuring the roots, but even more emphatically by weighing them. That is to say, on contrasting the weight of the roots day after day with the weight of the stems and leaves, it has been found that, while the proportion of roots is very large when the plant is young, it diminishes constantly as the plant grows older. In the case of annual plants, the formation of roots seems to be finished by the time when ripening begins.

Schubart found that garden peas sown early in April, in stiff loam, had roots 10 to 13½ inches long at the end of a month, and 20 to 22 inches at the end of two months. When the plants were in blossom, their roots were 4 feet long.

Clover, examined at the beginning of April, the year after it had been sown, in not very heavy loam, had roots 3 ft. 6 in. long; while that sown two years before had roots 3 ft. 10 in. long.

The roots of orchard grass and timothy have been traced to depths of 4½ feet, and those of other grasses, notably English ray grass, to a depth of 4 feet Rhenish.

Heinrich also grew plants of barley, oats, and peas in separate boxes, 13 feet deep, that were filled with sifted garden earth, and finally washed away the earth from the roots of the ripe plants. His results are given in the table.

Plant.	Length of Roots.	Weight of Air-dried Roots.	Weight of Air-dried Straw and Chaff.
	Feet.	Grams.	Grams.
Oats	7½	43.75	61.5
Barley	6¼	27.50	76.5
Peas	1¾	6.00	31.5

Heinrich argues from these results, and from the behavior of the two crops in field culture, that the roots of oats are probably better able than those of barley to overcome obstacles in the soil.

Volume of Grain Roots.

Hellriegel, in his turn, in order to get an idea as to the volume of roots of grain plants, grew barley and oats in large jars of fertile earth whence he washed out and measured the roots. Expressing his results in terms of total length, he found that the roots of a single well-grown mature barley plant, laid out as a single straight line, were more than 140 feet long. In another trial, where the soil was less fertile and the growth of the plants less satisfactory, the length of root was 80 feet to the plant.

In general, as would naturally be expected, the smaller the plant, so much the shorter will be its roots. The roots of the oat plant he found to be 164 feet long at that period of growth when the stem was beginning to shoot, 125 feet when the plant was in blossom, and 150 feet when it was ripe. The fact that fewer roots were found as the plant grew older is attributable in part, perhaps, to imperfections in the method of measurement, and in part to the premature dying of some of the roots in the jars of earth in which the plants were grown.

The most surprising fact brought out by the research, however, was the completeness with which the roots of these grain plants pervaded all parts of the earth which was at their disposal in the jars. In garden earth, for example, 200,000 millimetres of barley roots occupied 3,800,000 cubic mm. of soil, i. e. there was 1 mm. of root to every 19 cubic mm. of earth. In other words, each millimetre of root had at its disposal a cylinder of earth 1 mm. high and 5 mm. in diameter, or it might be said that on either side of the root there was no more than 2½ mm. of earth.

In the case of oats, each mm. of root had rather less than 21 cubic mm. of earth at its disposal. In fertilized sand the utilization of space by the roots was even more remarkable, each mm. of the roots of middle-aged and mature barley plants having here no more than 7.7 mm. sand at its disposal.

Roots of Peas, Beans, and Lupines.

Hellriegel studied the forms of pea, lupine, and horse-bean roots by growing the plants in moistened sawdust that had been slightly compressed, and obtained results of no little interest.

The pea has a strong tap-root, which is covered thickly and tolerably regularly from the beginning with lateral roots, most of which start from the crown or oldest part of the tap-root. A comparatively small number of the subordinate roots grow rapidly, and attain considerable length. The formation of side roots springing from the tap-root continues with tolerable regularity as the plant grows older, though these side roots are now not so close together as they were at the crown. The throwing out of some exceptionally vigorous lateral roots is a characteristic peculiarity of the pea, and some of these roots grow to be as long and as large as the tap-root itself, and they have as many rootlets also. The general effect of the pea roots is that presented by a stem very thickly beset with branches. The appearance of the roots indicates that any damage or disturbance experienced at one part of the net or mat would quickly be made good or compensated for by the action of some other part; and this supposition was found to be correct, on placing obstructions in the way of the roots.

The bean, like the pea, sends down a strong tap-root, from the crown of which numberless side roots are thrown off, with great regularity. These side roots are stronger and stiffer than those of the pea, and their growth is more uniform and less energetic than is the case with pea roots. As the tap-root extends downward, the side roots are thrown out at wider and wider intervals, so that the thickness of the root-mat diminishes from above downward.

Each of the the side roots of the bean grows about as fast as the others, and the absence of exceptionally long and powerful roots distinguishes the bean very clearly from the pea. The general appearance of the bean roots is that of a symmetrical cone inverted, with a dominant tap-root at the centre. So well provided is the bean plant with roots, that it is not likely to suffer much harm when partial obstructions are encountered in the soil, or when some of the rootlets are injured; but the tap-root of the bean is so much more prominent and important than that of the pea, that any injury to this organ, or impediment in the way of it, would do harm.

The yellow lupine has very different roots from either peas or beans. There is first of all a thick, powerful, hairy tap-root, which goes down to a considerable depth before any lateral roots are thrown out. About the time when the third leaf appears, side roots begin to be sent out from the lower half of the tap-root, often from the lowest quarter of it; but these side roots are extremely sparse and irregular. As the plant grows larger, the tap-root still remains dominant, though side roots grow rather more freely than before. They never get to be so thick as those which spring from the crown of the tap-root of peas and beans.

Unlike peas and beans, the most energetic growth of the lupine root is not at the top or oldest part of the root, but below, far away from the crown, and this peculiarity becomes more and more evident as the plant grows older. As compared with the highly symmetrical bean roots, those of the lupine appear irregular and confused. It seems probable that the loss of rootlets would be felt much more keenly by lupines than by peas or beans, and that the plant is consequently less well fitted to cope with mechanical obstructions than either of them.

Clover Roots.

The roots of red clover are said to resemble those of the pea in outward appearance. The clover plant develops a full set of roots during the first year of its life, as if it were an annual plant, and in subsequent years there is an analogous development of roots every spring after the plant has first thrown out the shoots which come from the store of nourishment that has been kept over winter in the tap-root.

When the crop is mown, the case is somewhat different. By growing clover in glass jars it can be seen that every time the plants are mown they enter upon a new course of life. Before a single leaf or shoot appears above ground, there is an energetic exhibition of new life below the surface of the earth, where a multitude of rootlets are thrown out in every direction; whence it seems plain, that the soil at the disposition of a clover plant must finally come to be pretty fully occupied with rootlets.

From the very fact, then, that the clovers are perennial plants, it would appear that they must take up food in a somewhat different way from the ordinary annual plants, such as wheat or oats. The roots of annuals die as soon as the seed has ripened. They have but a single season in which to accomplish the work of a life. But the roots of perennial plants live on year after year, and they send out new roots and rootlets with considerable freedom on occasion. Hence it happens that, although the roots of perennial plants do not necessarily, or even habitually, go deeper than those of annuals, they occupy space in a different way, and probably occupy it more fully. It is not likely that the soil invaded by each new set of roots which are thrown out by clover, for example, is precisely the same soil as that occupied by the previous sets of roots, so that it may be said fairly enough that food is continually extracted from new stores.

In other words, it may be said that the complex of roots of a perennial plant has had opportunity during the life of the plant to collect food from a much larger volume of earth than could possibly have been drawn upon by the roots of a single annual crop. Moreover, it is not unreasonable to suppose that plants already equipped with a well-developed system of roots may have a certain advantage over young annuals in times of drought. If the surface soil should become dry, the roots of perennials would naturally draw food as well as water from below, while in case the subsoil were over wet, the roots would find food at a higher level. If there happens to be but little plant-food in the soil, the crops whose roots most completely fill the soil will have the best opportunity to extract what food there is. All this, beside the habit common to most perennial plants of storing up in their bulbs or tap-roots a supply of food for next year's use.

In speaking thus of the complex of roots of a perennial plant, it is important not to detract from or confuse in the least the fundamental conception that the food of plants is taken in for the most part by young and delicate rootlets, and by the little hairs which cover the rootlets. All is, the more roots there are, the more rootlets will there be or have been; or, rather, the more roots there are, the better and the more complete will the distribution of the rootlets be.

Importance of thorough Distribution of Roots.

The foregoing conception is worthy of careful consideration. Thus, the plant itself is immovable. It needs certain kinds and amounts of food that must be taken from the earth. This food is taken in through certain active cells situated for the most part near the ends of the rootlets. Hence it is evident, unless the soil should happen to be extremely rich, that rootlets should be sent out and scattered in every direction in order that their work may be accomplished to the best advantage.

There follows naturally from this conception one important lesson as to the theory of manuring. For inasmuch as it is plain that the absorbent rootlets can never occupy every part of the soil in which their plant is standing, it is certain that the plants of one single particular crop can never by any possibility take up all the food which the soil contains. Hence, in applying manure to a poor soil, it will not do to argue that the land will be properly treated if there be put upon it precisely as much and as many fertilizing materials as the crop will take off. It is not in any man's power to put a limited amount of fertilizing materials in precisely the same places as those from which a crop has taken, or will take, its food. Consequently, in order to manure poor land well, it must be manured tolerably heavily. Generally speaking, it would doubtless be the part of wisdom to try to keep all plough-land in such condition that it should contain in the aggregate an amount of available plant-food equal to a considerable multiple of what any single crop could take off; because, no matter how carefully the land may be tilled, no one crop can ever gain access to every part of the land. But since no crop can ever reach the whole of the food, care should be taken to have such an excess of food in the soil that the crop can find within reach as much food as it wants. This argument may be seen pushed to its uttermost limits in the practice of market gardeners, who are accustomed to employ stable manure in such enormous excess that their crops cannot possibly consume any large fraction of the plant-food that is contained in the manure.

Manuring maintains Fertility.

Properly considered, the purpose of manuring in ordinary farm practice is to keep up the fertility of the fields, and to maintain in the soil a proper amount of fermentation, rather than to create fertility. It is the natural strength of the land that insures the necessary excess or multiple of plant-food; and, by manuring, compensation is made for what has been taken away, as well as provision for maintaining the excess. It is conceivable, of course, when the natural strength of land is great, that the fertility of such land can be kept up by adding to it no more than precisely what the crop has taken off, or even by adding less than the crop has taken off.

Experiments made by Eckenbrecher illustrate the fact that lupines are better able than oats to take food from the subsoil. Bottomless boxes, or frames, were sunk in the ground, and filled with sterile sand, so that some plants could be grown in a layer of sand 1½ feet deep, and others in sand 3 feet deep. No nitrogenous manure was added to the sand, but only the ash ingredients necessary for plant growth. Into the subsoil, however, nitrate of soda was stirred, in both cases, at the rate of 67 grams to the square yard of surface. There were harvested grams of air-dried plants, —

	From ½ Yard Depth of Sand.	From 1 Yard Depth of Sand.
Oats (*a*)	677	220
Oats (*b*)	405	160
White lupines	1,398	837
Yellow lupines	1,147	687

Whence it appears that lupines are better able to utilize deeply buried nitrates than oats, although both crops would have been well suited if the fertilizer had been somewhat nearer the surface.

Development of Roots at different Depths.

Hellriegel studied the development of the roots of plants in still another way, and obtained results which are specially interesting as illustrating the very great influence which the character of a soil may have on the manner of growth of the roots within it.

An earth-borer, made of strong sheet-iron, which was nearly nine inches in diameter in the clear and some ten inches high, was thrust into the soil of the field where the crop to be examined was growing; the soil outside the borer was then dug away, and the latter turned down to break off the core of earth within it. The root fibres at the bottom of the core of earth were then counted, the earth was shaken out from the borer, and the instrument again thrust into the soil at the very place from above which the previous core of earth had been taken. The process of boring was thus repeated until no more root fibres could be found in the earth. The circle of earth cut out by the borer measured 62 square inches, and the numbers of root fibres enumerated below all refer to this area. The borings were made at times when the plants were in blossom, or just about to blossom, i. e. at a moment when the roots would naturally be fully developed. Some of the trials were on high-lying land, 13 to 100 feet above the ground-water, and others were on low-lying land, where the ground-water was not very far off.

I. *Winter Wheat* on high land. The soil consisted of two feet of loamy sand overlying coarse gravelly sand. The soil proper contained humus to the depth of a foot, but the second foot of soil had no humus. There were found at a depth of

8	inches	(in the loam)	820 root fibres.
21	"	(in loamy sand)	200 " "
31	"	(in gravelly sand)	26 " "
39	"	(in gravelly sand)	0 " "

II. *Winter Wheat* on low land. The soil of field "A" was rich in humus at the surface, and consisted of a foot of sandy loam, below which there were one to two feet of clayey river loam overlying clear sand. There were found at a depth of

8	inches	(in the soil proper)	558	root fibres.
15	"	(in river loam)	218	" "
26	"	(in sand)	83	" "
33	"	(in sand)	106	" "
41	"	(water table)	0	" "

In another low-lying wheat field, "B," the soil consisted of peaty humus to a depth of 17 inches, with a subsoil of 7 inches poor in humus, beneath which was a layer 2 or 3 feet thick of coarse gravel overlying blue plastic clay. Here there were found at a depth of

8	inches	(in the loam)	432	root fibres.
17	"	(in clayey sand)	344	" "
23	"	(in clayey sand)	149	" "
31	"	(in gravel)	119	" "
39	"	(in clay)	98	" "
48	"	(water table)	0	" "

III. *Red Clover* in the second year of its growth, on high land. The soil consisted of two feet of loamy sand overlying coarse sand. The upper half of the soil proper contained humus, and the lower half none. There were found at a depth of

9	inches	(in the loam)	874	root fibres.
18	"	(in loamy sand)	340	" "
26	"	(in loamy sand)	185	" "
32	"	(in coarse sand)	26	" "
41	"	(in coarse sand)	10	" "

IV. *Red Clover* on low-lying land. The soil consisted of sandy loam three feet deep, of which the uppermost 18 inches contained humus. Below the sandy loam there were 3 to 3½ feet of clayey river loam, and below that clean sand. There were found at a depth of

9	inches	(in the loam)	729	root fibres.
20	"	(in the sandy loam)	87	" "
24	"	(in the sandy loam)	56	" "
32	"	(in river loam)	34	" "
40	"	(in river loam)	32	" "
43	"	(in the sand)	74	" "
51	"	(water table)	0	" "

Similar trials were made in fields of oats, barley, rape, lucern, lupines, and winter rye, with analogous results. It appeared from these experiments and others, that rape plants had the largest number of subordinate roots (1,275 fibres were counted at a depth of 9, and 685 at a depth of 17 inches), and that flax and buckwheat came next. Then came the different kinds of clover, peas, and beans. After them came the various kinds of grain, and finally lupines, which had the least number of roots of all the plants examined.

No marked differences were noticed as to the depths reached by the roots of different kinds of plants, and it seems plain that the agricultural plants do not differ from one another much in respect to this particular. On the high-lying land, the great mass of roots of all the crops were found in the soil proper, i. e. in the more fertile and porous layers near the surface; and even in the low-lying fields only a small proportion of the roots went down to the poorer subsoil, — not more than about 10% of them.

It will be noticed that the low clover field, and one of the wheat fields above cited, are exceptions to the general rule, that the number of roots diminished regularly with the depth. In both these instances a considerable number of roots were developed in the lower moist sand after the plant had been at the trouble of pushing through the clayey loam of the subsoil. But, as a general rule, only scattering root fibres were found in this poor land at depths greater than three feet. Undoubtedly, a very different state of things would have been met with, if similar trials had been made, in deep moist loams.

Crops may consume Food at different Times.

Not only do different crops require different amounts of food in order to come to maturity, but since the life of some kinds of plants is shorter than that of others, one kind of crop may require a richer soil than the other kind; not because it removes more food from the land in the aggregate, but because it requires more food in a given time.

Ashes of certain Crops.

The following table, drawn up by Professor Johnson, gives the average contents, in per cents, of fertilizers in the ashes of several common crops.

		Alkalies.	Magnesia.	Lime.	Phosph. Acid.
CEREALS.	Grain (without husk) .	30	12	3	46
	Straw	13–27	3	7	5
LEGUMES.	Kernel	44	7	5	35
	Straw	27–41	7	25–39	8
ROOT CROPS.	Roots	60	3–9	6–12	8–18
	Tops	37	3–16	10–35	3–8
GRASSES.	In flower	33	4	8	8

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Fertilizing Matters carried off by Crops.

The following table, likewise copied from Johnson, gives the weight in pounds of produce taken annually from an acre of good land by the several crops, as well as the weight of the more important constituents in these crops.

		Crop.	Nitrogen.	Ashes.	Phosph. Acid.	Potash.
WHEAT.	Grain . . .	1,840	34	32	15	10
	Straw . . .	4,600	14	207	8	39
	Sum . . .	6,440	48	239	23	49
RYE.	Grain . . .	1,470	28	25	12	9
	Straw . . .	3,500	12	140	4	27
	Sum . . .	4,970	40	165	16	36
BEANS.	Seeds . . .	1,840	76	60	20	27
	Straw . . .	2,700	33	138	14	34
	Sum . . .	4,540	109	198	34	61
BEETS.	Roots . . .	36,800	88	353	22	158
	Tops	9,200	26	173	11	69
	Sum . . .	46,000	114	526	33	227
CLOVER		6,000	130	390	25	105
GRASS		4,000	53	246	13	58

The rye crop takes only one third as much nitrogen as a clover crop or a beet crop. Wheat takes twice as much phosphoric acid as grass, and two thirds as much as beans and beets. About the same quantity of potash goes off the field in wheat as in grass, though it does not necessarily go off the farm, while beets and clover take up a good deal more potash than grass.

It is to be observed that tables such as these do not teach, as has sometimes been supposed, what manures to apply in any particular case to either of the crops in question; for the soil might contain already an abundance of most of the things needed, and the plant still fail to thrive, because some one essential ingredient is absent.

It is true, moreover, as has been said, that different plants have very different powers as to getting at, extracting, and using the stores of food which may be contained naturally in any soil; and in general it appears that each particular kind of crop acts in its own peculiar way upon the land, and takes away from the soil, or from the manure which has been applied to it, more or less of each one of the substances which are necessary for the growth of plants. Hence the advantage, under ordinary circumstances, of varying from year to year the kind of crop grown upon any given field. If one and the same crop were to be grown year after year upon the same piece of land, there would be a tendency to reduce unduly the proportion of the substances which are preferred by this crop, or which can be extracted from the soil by this crop. The tendency would be to accumulate in the soil those substances for which this crop has least need. In ordinary language, there would be risk of exhausting the soil to such an extent that the crop in question could no longer be grown upon it. But by planting different kinds of crops from year to year, the preferences of one kind of plant may be made to counterbalance in some measure those of another, in such manner that the tendency to exhaustion may be greatly abated, or even annulled.

Meaning of the Word Exhaustion.

It needs to be said, perhaps, that the word "exhaustion," as used in agriculture, has no very precise meaning. It is a term based on money values, rather than on scientific conceptions. It is true enough that, in many situations, land may be utterly ruined by improper or careless cultivation, such as permits the surface soil to be washed away bodily by rains. But no such destruction as this can be reached by any system of mere cropping, no matter how ill considered it may be. Strictly speaking, a soil is exhausted, as regards any particular crop, whenever the cost of cultivation comes to as much as the crop is worth.

The value of a crop depends upon the demand for it, and the cost of carrying it to meet the demand. In the vicinity of Boston, for example, rye is a profitable crop, because of the brisk demand for straw; but, owing to the cost of transporting this bulky commodity, there might be little or no profit in growing rye as a field crop a few miles farther back in the country. Hence it might be said with truth in some places, 30 or 40 miles distant from the city, that the land is "exhausted," and will not grow rye, although that very land may be capable of yielding more rye and more straw to the acre, and at less cost, than the land upon which rye is profitably grown near the market.

Fairy Rings.

One striking illustration of the significance of rotation is afforded by the so-called fairy rings, in old grass fields. These fairy rings are circles of grass of coarser growth and greener color than the grass on the remainder of the field. They are caused by the growth of a fungus, which, starting from a spore which happens to have been sown at a particular point, grows, bears fruit, and dies, and by its decay affords nourishment to the grass. Subsequently a new crop of the fungus springs up around the original central point, from spores shed by the first plant, and afterwards still another crop grows just outside the first ring, and so the process goes on for a long term of years, the ring being constantly enlarged until some accident destroys it.

The English chemist Wollaston suggested long ago that the reason of this peculiar growth is, that the fungus exhausts the soil of some essential ingredient, so that the spores which fall upon that spot find it to all intents and purposes a desert. But, on the other hand, the grass finds a richly manured soil where the fungus has just decayed; and since the fungus contains much nitrogen, the grass takes on the deep green color due to nitrogenous manures.

Practical Rules for Rotation.

From considerations such as have been urged above, several agricultural writers have laid down the principles of rotation in the following terms: —

Every plant exhausts the soil, when carried off from it.

But all plants do not exhaust the soil equally. Nor do different plants exhaust the soil in the same manner.

Even when fed out upon the farm, all plants do not restore to the soil the same quantity nor the same quality of manure.

Finally, all crops are not equally favorable to the growth of weeds, the nourishment of fungi or insects, or to the tilth of the land.

Rotation is often Unnecessary.

It is possible, of course, in many cases, to do away with rotation, by manuring the land freely with the things best suited to the crop we wish to grow. Illustrations of this fact are seen every day in asparagus beds, and in the old fields and pastures of Europe also. It is claimed, indeed, as one particular advantage of asparagus, that it is a plant which will produce crops for twenty years in succession without renewal. So, too, farmers are apt to grow carrots year after year upon one and the same field; and a similar remark is true of onions and celery, and of the Lima bean in the Middle States. It is true of rhubarb also, and of some other garden plants.

It is no uncommon thing, in Europe, to grow potatoes year after year, or with infrequent omissions, on the same fields, in localities where the tubers are used for distilling, or for making starch or glucose; and it has been found that this practice may be persisted in without any particular diminution of the yield, provided, of course, the fertility of the soil is kept up by manuring. Boussingault narrated long ago, that in South America potatoes are habitually grown on the same land without interruption, and that the crops obtained are of excellent quality. All this, in spite of the well-known fact that in New England potatoes often grow best on new land which has just been turned up from pasture, — probably because of the superior fertility of such land, and of its freedom from some kinds of worms.

Boussingault mentions, that maize also has been grown incessantly in many parts of Peru, since a period long anterior to the discovery of America; and that on the plateaus of the Andes there are wheat-fields which have annually given good crops for more than two centuries. Indigo, sugar-cane, and Jerusalem artichokes are other crops which are seldom or never rotated.

Indeed, there are many crops that might be grown for almost any number of years consecutively on the same land, provided that money and labor enough were expended in putting the soil into the proper chemical and physical conditions. But to do this would usually cost more than to rotate the crops. At all events, it has hitherto been found more profitable in the main to combine the rotation of field crops with the judicious use of manures.

Some Crops prefer New Land.

The fact must not be lost sight of, that, in direct opposition to what has just been said of carrots and asparagus, there are some plants that succeed very much better on new land. Strawberries, for example, grow luxuriantly on new land; but after a few years they tend to degenerate, and are supposed to need a fresh soil. In like manner it is noticed by practical men, that — while there are some plants which seem to have no need of humus, such as the Teltow turnip for example, or most emphatically the potato, which often does extremely well on mere gravel or sand, if only it be supplied with dung and water — there are other plants that prosper best on soils rich in humus, notably celery, cauliflower, and the rutabaga.

Another special instance that should be mentioned when speaking of new land is the behavior of the common plum tree. It is well known in New England that the plum formerly succeeded perfectly when the country was new, and that it can be grown to-day successfully in the wild forest regions of New Hampshire. The market in Boston is supplied every summer with damsons from Nova Scotia; but in proportion as the country grows older, the plum trees cease to thrive.

It may possibly be true, as some writers have urged, that the plum trees have exhausted the soil, and that they really need new land. But, to my own mind, no such hypothesis is tenable. The plum tree grows perfectly well upon the continent of Europe, and yields abundant crops of fruit, even upon land that has been the longest cultivated. It does not thrive here because of various and vigorous enemies, both of insect and of vegetable origin. Probably, if we could but circumvent the curculio and the black-knot fungus, plums might be grown freely enough with the aid of proper manure. But, as things are now, the only economical way of proceeding is to take refuge in the backwoods, and establish the plum orchards in districts free from those kinds of wild-cherry trees in which the black-knot harbors, and where the curculio is rare.

Rotation not needed in some Situations.

In very rich land, of not too fine texture, there is often little or no need of rotation. Most gardens are so fertile that the rotation of crops in them would have no significance except as a means of avoiding some insect, or fungus, or weeds, or the impaction of the land. As was just now said, Boussingault tells of land in South America on which grain has been grown incessantly during 200 years, and Gasparin describes fields in the South of France which have yielded excellent grain crops for 40 successive years. Such lands as these occur exceptionally in some parts of the West, notably upon river bottoms. In the vicinity of large cities, also, where manure is abundant, there has never been felt so strong a need of rotation as in the districts which are distinctly rural. A similar remark will apply to countries made fertile by irrigation, and to a certain extent to those manured with sea-weeds.

An interesting system of small-way farming, based upon sea manure, has recently been cited as common at the North of Scotland and on the adjacent islands. There are numerous "crofters," as they are called, i. e. men who hold about five acres of land on the average. They have also a right to pasture sheep and cattle on the commons, such as they are, but they get their living chiefly from the sea, or by working in England in the summer. Their usual method of husbandry is to keep three fourths of their land in oats, and the other quarter in potatoes. But the oats are heavily manured with sea manure, and the potatoes with cow dung together with a little guano, since sea manure is not good for potatoes in cold countries. The three crops of oats come one after another, and the potatoes succeed them. In some cases where the land is too wet for potatoes, oats are grown incessantly for a dozen years at a time, and are manured all the while with sea manure. The straw of the oat crop, together with hay, is given to animals in the winter, while oat-meal and potatoes serve as human food.

Fallow Fields.

It must be remembered always, when speaking of rotation, that the natural disintegration and decomposition of matters within the soil tends to counterbalance the exhaustion produced by cropping. Practically this fact has always been recognized. In many of the older systems of rotation, for example, it was customary to let the land lie fallow every second or third year. Sometimes the fallow fields were left absolutely to themselves; but in the better systems of husbandry they were ploughed frequently, so as to hasten the process of disintegration and nitrification, as well as to destroy weeds and to turn their constituents to profit as green manure. The destruction of insects also was sometimes a point of considerable importance. For example, one good way of clearing a field of the pernicious white grubs of the dorbug, or June beetle, is to fallow and work the land thoroughly for a season. Not only will the processes of ploughing and harrowing bring many of the grubs to the surface, there to be devoured by birds, but there will be nothing left for the grubs to feed upon if the land is kept bare of vegetation.

Fallowing was commonly practised by the Romans even. In most cases they left the field fallow for a year after taking a crop; though, when manure could be got, they sometimes took two or more crops in succession, and then left the land fallow. The length of time that the fallow fields are left to themselves varies widely in different countries. In poor wild countries, such as some parts of America and of Russia also, it is no uncommon thing to take one crop and then throw the land away, as it were, i. e. leave it without thought of ever using it again. In the Lunenburg heath, in Germany, there are places where the land is regularly burned over every twenty years, and one crop taken from the land. This case might be described as a rotation of 1 grain crop and 19 fallow fields. In the moorland of North Germany 1 crop and 12 years of fallow is no uncommon course. In some parts of Spain two or three fallow years between every two crops are common. In some parts of Sweden the peasants leave half their land fallow every year, while upon the other half they sow grain, and they manure one seventh of the fallow land every year.

It is manifest, however, that disintegration must be going on to some extent during the growth and the tilling of crops. Where land has once been brought into good condition, the amount of this disintegration may every year be sufficient to keep up the supply of mineral matters necessary for the growth of the crop. This idea lies at the base of the so-called drill-husbandry, i. e. the horse-hoeing of Jethro Tull, and of the Lois-Weedon system of our own time, as well as of most modern systems of rotation. The very word "manure," as has been said already, originally meant manœuvre (hand work), i. e. it meant to dig, to till, to cultivate, and thereby to disintegrate.

The experiments of Lawes and Gilbert bear very forcibly upon this point. Upon a soil described by them as of not more than average wheat-producing quality, they grew wheat successfully without any manure for forty and more years in succession. The product of dressed grain was 17¼ bushels to the acre the first year, and 15 bushels the twentieth year, and 16¼ bushels as the average of the first twenty years. Before this land was set apart for the wheat experiments, it had been cropped five times since any manure was put upon it. But, in spite of all this, the soil was in such condition that the amount of matter made available as wheat-food within it, by disintegration and by nitrification, in the course of the year, was very nearly or quite equal to the amount of such matter removed by the crop.

Natural Strength of Land.

It is to be observed, of course, that this natural process of supplying food could hardly be possible excepting on land fertile enough to be in some sense a reservoir of food. The process of supply and demand cannot here be coincident and equal day by day. The disintegration which occurs in the course of a single summer's day may be wholly insufficient to supply the crop with food on that particular day, and yet, taking the entire year, the disintegration might be largely in excess of what the crop needs or can consume.

This idea of disintegration supplying to the soil what is taken off in the crops, bears directly on what farmers call the "natural strength" of land. There are some soils which, thanks to the incessant action of disintegrating influences upon fit materials, will bear cropping; and there are others that will not, because of the absence of this agency. In wooded districts, such as those not far from Boston on the south shore of Massachusetts Bay, and in the so called Old Colony, notably on the Blue Hills, within sight of the Bussey Institution, it is customary to cut down the trees every 20 or 30 or 40 years, and to allow a new forest to grow from the sprouts which shoot up from the old stumps. "Sprout-land" the New Englander calls it. It is known as Coppice in English, French, and German.

It does not appear that there is any great variation from one century to another in the quantity of wood grown upon a given number of acres of the woodland in the course of the 25 or 30 years required to mature the crop. But evidently the conditions of disintegration in the woodland, as well as upon the experimental fields of Lawes and Gilbert, are such that a supply of food is kept up for the use of the crop. The only difference is, that in the woodland the plants seek their food at comparatively great depths and over wide areas, and are so constituted that they can grow slowly. Hence the soil need not be rich in the beginning, nor the disintegration rapid from year to year. But for the growth of the less robust wheat plant the conditions must be more favorable.

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CHAPTER XII.

SPECIAL SYSTEMS OF ROTATION.

Why Rotation was first practised.

It should be clearly understood that the practice of rotating crops is not by any means based upon chemical or botanical considerations alone. It is really a relic from the time of Village Communities. It is true, indeed, that several noted writers of antiquity held views in regard to rotation which are in accordance with principles now known to be correct. Xenophon speaks of a two years' rotation of wheat and fallow, and Cato and Varro and Virgil tell of the alternate culture of grain and legumes. But as now practised, systems of rotation seem to have been derived directly from the times of village communities, rather than from the Roman civilization. They may be said to be in the main inherited from the "common fields" of village communities, where rotations were made necessary in the first place by the system of holding land which prevailed.

In the days when the village, and not the individual, had the management of private affairs, the practice was, that instead of being enclosed as separate farms, all the plough-land was left open; and it was cultivated by many individuals, each one working for himself upon separate strips of the common tract, i. e. on pieces of land which were allotted to him for a single season. To avoid all conflict of interests, each of the large common fields was marked off into three great parts, one of which parts was devoted, one year in three, to winter grain (i. e. to wheat or rye sown in autumn); another part of the field was devoted to summer grain (barley or oats sown in spring), while the third part was left fallow. This was the old "three-course" system of rotation, which through many centuries was practised almost universally in the more fertile parts of Europe.

So long as the system of common unenclosed fields prevailed, it was impossible for any one person to deviate from the established practice; especially as there was usually a common right of pasturage upon the fallow field throughout the year, and upon each of the other fields after harvest. It appears, indeed, that individuals were not allowed to deviate from the established course, and in later times one of the worst impediments with which the progress of rational agriculture has had to contend has been the tendency of European landlords to compel their tenants to hold fast to established systems of rotation. It has been said, in fact, that no real improvement was introduced into the agriculture of many districts of England until the notion of the perfection of the three-course system was exploded, and tenants were permitted to deviate from it.

Starting in this way from a mere social and physical necessity, the continuance of systems of rotation has always depended in good part upon established customs made rigid by legal forms. In the majority of cases, perhaps, tradition has had more to do with the maintenance of rotations than have any scientific conceptions as to the reason of them, or any just deductions from the results of practical experience.

The Three-course Rotation.

In the original three-course system there was usually maintained in connection with the ploughed land, which was given over to grain, a large tract of wild pasture, where cattle, sheep, hogs, and geese were tended by shepherds, herdsmen, and the hog-reeve; and there was another tract of permanent meadow, where grass was mown for hay. Where these arrangements existed, it was possible to get dung enough from the cattle, and from folding sheep, to give the fallow field a dressing of manure; that is to say, the ploughland was manured every third year, since one third of it was manured each year. But in other instances, where the supply of dung was small, — and this would naturally be the case as population increased, and the ploughed land came to encroach upon the meadow and pasture, — the common field was divided into twice as many parts as before, and manure was applied only half as often; i. e. every other fallow was dressed with dung, so that the land received manure only once in six years.

The three-course system is commended by its great regularity and simplicity, and by the possibility of cultivating land in a wholesale way at small cost for supervision and labor, and is upon the whole not ill adapted for a primitive state of society. It is manifestly incompatible, however, with the existence of a dense population, and would not be advantageous for a scattered population living upon separate farms. Excepting in fertile regions, the two grain crops in succession would tend to exhaust the soil too readily.

Derivation of other Systems from the Three-course Plan.

As regards the derivation of other systems of rotation from the old three-course plan, it may be conceived that, as population and the consequent demand for grain increased, the pastures in fertile districts were gradually ploughed up and converted into arable land, and that, as a consequence, comparatively few cattle could be supported. Hence, so little manure was obtained that the crops suffered, the land was after a while run out, and emigration became necessary. But, on being left to itself, the land soon reverted naturally to the state of pasture, cattle were again kept, and dung was again produced. To maintain the cattle, the significance of which as producers of dung and flesh was now apparent, regular fields of sown grass were established.

Grass Rotations.

As would naturally be expected, the introduction of grass into the regular system of rotation first appeared in countries specially fitted for grazing. It seems to have been first practised extensively in Holstein and Mecklenburg, and it soon raised these countries to a high place among the agricultural nations. It has been employed in Scotland also, and in the Midland Counties of England since a very early period.

The idea of the grass rotation is simply to have fields of artificial pasture (maintained for several years) alternate with grain. The system has been found to answer exceedingly well, not only in the localities just mentioned, but in various others where the climate is so moist that grass grows freely and unchecked by drought, and where the land is so free from stones that most of it can be brought under the plough. It is practised, for example, upon the rainy uplands of Bavaria and Saxony, as well as in the lowlands of the North of Germany and Denmark. There are many varieties of this system of grass rotation. Thus, in Holstein, one way is: 1. Oats on the newly-broken grass land; 2. A fallow to destroy grass and weeds; 3. Wheat, with or without manure, according to the state of the land; 4. Barley; 5. Rye, lightly manured; 6. Oats with clover; 7 and 8. Pasture.

An old Scotch rotation was: fallow; wheat; grass, fed for one, two, or three years; then oats, peas, or beans, and wheat again. A simpler system, followed in the Styrian uplands, is: 1. Summer rye, with manure; 2. Oats; 3. Winter rye, with manure; 4, 5, and 6. Grass land. This last has a certain resemblance to a course not unusual in the vicinity of Boston, viz.: 1. Grass for mowing, kept down for six or eight years, or as long as the grass continues to give a fair yield; 2. Winter rye, on the inverted sod, without manure; 3. Indian corn, potatoes, or sometimes roots, i. e. a hoed crop, well manured; 4. Seed down to grass again, with rye, unless the land is so foul that another year of cultivation is needed to destroy the weeds.

A common course in Western New York is said to be: 1. Indian corn on sod, with manure; 2. Barley or oats; 3. Wheat; 4. Clover, mown first for hay, and afterwards for seed; 5. Clover and timothy mown for hay. Another course, practised in the northern part of New York, is: 1. Oats on sod land; 2. Part Indian corn, part potatoes, and part roots; 3. Barley or spring wheat; 4, 5, and

6. Clover or grass, i. e. timothy. An old system, employed in the Midland Counties of England, was: 1. Oats on the sod; 2. Wheat; 3. Barley sown with grass; 4. Pasture for 7 or 8 years.

Not many definite rotations have ever been established in New England. One very old one, commended for heavy land, was: 1. Oats; 2. Potatoes, well dunged; 3. Flax or wheat; 4. Grass, for as many years as possible. General Washington, writing of the western end of Long Island, in 1790, says: Their general mode of cropping is: 1. Indian corn upon a lay, manured in the hill, half a shovelful in each hole, though some scatter the dung over the field equally; 2. Oats and flax; 3. Wheat, with what manure they can spare from the Indian corn land. With the wheat, or on it, towards the close of the snows, they sow clover, from 4 to 6 lb., and a quart of timothy seed. This lays from 3 to 6 years, according as the grass remains, or as the condition of the ground is; for, as soon as they find it beginning to bind, they plough.

Mr. Mitchell has suggested: 1. Corn, cut young for fodder, the earlier cuttings being followed by turnips; 2. Part carrots, part mangolds, and part potatoes; 3. Oats or other cereal; 4. Clover and grass, to be kept down as long as possible. For soiling cows, in summer, he suggests pasture grass from May 10 to June 10; then mown winter rye; then lucern; then clover and orchard grass; then fodder corn; and, finally, late-sown barley, and the leaves of root crops, which, as will be seen, would involve a tolerably complex arrangement of crops.

An Alabama rotation is: 1 and 2. Clover; 3. Corn; 4. Wheat; 5 and 6. Cotton.

Some readable speculations on one of the old varieties of grass rotation, as practised in the Roman Campagna, may be found in the second volume of Mr. George S. Hillard's "Six Months in Italy."

At the present day the old grass system, such as has here been described, would be intolerable in any country other than those which, from excessive moisture or mediocre soil, are forced to devote themselves to the business of grazing. The chief advantage of the system is found in the fact that the land can be kept in tolerable condition with a comparatively small expenditure of labor, and in tolerably good case withal, through the droppings of the cattle which are pastured or fed upon it. But it is impossible in this way to work good land to its utmost capacity.

Pasturing good Land refreshes it.

From the chemical point of view, the significance of the introduction of grass-land into courses of rotation is, that the pastured grass, so far from exhausting the soil, actually improves it. A grass field is, to all intents and purposes, a dwarf forest. If the grass or the trees are allowed to die and rot upon the land, the soil will become richer every year, because the roots of the plants bring up new stores of food from below to be deposited upon the surface, while the mat of grass sod, or of tree roots, and litter beneath the trees, shields the humus from oxidation, and prevents the finer portions of the soil from being washed away by rain. In the same way, land will improve when fatting cattle are pastured upon it; for the cattle that eat the grass restore to the soil all but a minute fraction of the mineral matters contained in their food, and a large proportion of the nitrogen also is put to profit by the grass.

Even when the grass is mown to be fed out upon the farm, either green or in the form of hay, the better part of the dung and urine will practically be carried back to the land. Consequently, the adoption of grass rotations in place of the three-course plan was a distinct gain for the land in all cases where the supply of manure obtained from outlying grass-lands, i. e. natural pastures and meadows, was insufficient to dress the ploughed fields.

It should be clearly understood that the grass system is still retained in several fertile countries, subject, however, to certain modifications. Thus, for example, in some parts of Saxony to-day, the course is: 1. Winter rye, with manure on the inverted sod; 2. Potatoes; 3. Wheat; 4. Clover; 5. Oats; 6. Peas, beans, or vetches, with dung; 7. Winter rye; 8. White clover with grass; 9 and 10. Pasture. Or: 1. Potatoes on the sod, with manure; 2. Rye; 3. Flax; 4. Wheat; 5. Oats; 6. Vetches; 7, 8, and 9. Pasture.

A five-course rotation, known as the Berwickshire course, has long been popular in the North of England and in Scotland. It consists of: 1. Wheat or oats; 2. Turnips or other roots; 3. Barley or oats; and 4 and 5. Clover and grass. There are seven-year Scotch courses essentially similar to this one, only that the grass is kept down four years instead of two.

The following Scotch rotations are practised to-day on farms not far from Edinburgh, the increasing demand for meat, and the increasing cost of labor tending both to keep up and to increase the grass system of husbandry in the moist climate of Scotland: 1. Oats; 2. Part potatoes and part beans; 3. Wheat; 4. Turnips; 5. Barley; 6. Hay or pasture. Many farmers, who have practised this course, are said to incline more and more to two years of pasture instead of one, as stated. Other farmers prefer: 1. Oats; 2. Part potatoes and part turnips; 3. Barley or wheat; 4. Hay; 5. Pasture. Others still have: 1. Oats; 2. Beans; 3. Wheat; 4. Turnips; 5. Barley; 6. Grass.

Farther from Edinburgh they have: 1. Oats; 2. Part potatoes and part turnips; 3. Wheat or barley; 4. Hay and grass; 5. Grass. Or on lighter land: 1. Oats or wheat; 2. Turnips; 3. Barley; 4, 5, and 6. Grass.

Rotation and Labor.

The idea of these improved systems of rotation, as of all the courses which have been adopted in the high farming of modern times, is to get from the land in a given time as many merchantable products as can possibly be obtained by the judicious expenditure of labor and capital. This remark suggests a point which has not been sufficiently discussed hitherto, viz. the judicious division and adjustment of labor upon the farm. Manifestly this consideration, in the absence of our modern machinery, must formerly have had a very important bearing upon the practice of rotation. In the old days of hand labor, the remark applied to all farms, — as it does still to farms devoted to several kinds of crops, — that the crops must be so arranged that the whole labor of seed-time shall not come at once; and that the times of ripening of the crops shall be different, in order to secure a succession of harvests.

It was a great point with the farmers to divide their labor so that it should be distributed as evenly as possible through the entire season. And so, conversely, when machinery came to the farmer's aid, the old systems of rotation had to be modified, in order that the machines might be worked to the best advantage. In this sense, Mr. Mechi has expressed his conviction that the old English four-course rotation must give way, especially on heavy lands, to a freer system. Under the old plan of ploughing with horses, and in the lack of artificial fertilizers, such a system was very well adapted to the circumstances, the horse-work being regularly diffused or apportioned over the whole year. But now that the land can be cultivated by means of steam ploughs, and manured with chemicals, the case is greatly altered. By using steam ploughs, the stubble fields can be broken up, and the winter crops got in with a rapidity formerly unknown; and so with other operations, such as threshing and harvesting.

To take a more familiar example, there is a certain incentive to grow rye in the immediate vicinity of Boston, because the long straw sells readily at a high price; and the question naturally arises, Why do not all the suburban farmers grow rye? The answer is, that there is small profit in growing this crop, unless the other crops of the farm, and the farm work, have been adjusted to this particular line of business. In case the farm has much hay to be cut, the rye harvest would fall at an inconvenient season, and interfere with haying. Labor has to be expended in threshing the rye, and perhaps in rehandling the straw after threshing and before selling it. And then, again, when sown with grass, the rye saps the land at the very time when it is desirable that the growth of the grass shall be particularly favored. Hence, if the farmer wishes to grow rye, he must cut and contrive accordingly; and so it is, of course, with every other crop. It has been repeatedly remarked by practical men, that, for large-way farmers, corn ensilage will be profitable only in those cases where the getting of it and the use of it do not conflict with the general plan of the farm, and with the utilization of unmerchantable products that are obtained upon the farm.

Other Green Crops than Grass.

Another way of meeting the lack of manure in the three-course system was to have more frequent fallows, which was at last tantamount to adopting a two-course rotation, viz.: 1. Grain; 2. Fallow. Possibly there may be situations even now where this plan would be the more economical, all things considered; though the idea on which it rests can hardly be regarded as philosophical.

Doubtless one of the reasons why bare fallows were resorted to by the forefathers was the scantiness of their list of agricultural plants. Probably at one time no field crops were known beside grain and grass. Even the addition of pulse seems to have been of the nature of a discovery and innovation, and it is known that the introduction of turnips, clover, potatoes, and maize, not to mention sugar beets, has greatly changed the agriculture of several European nations. Experience had taught that, with the methods of manuring employed in those days, grain could not be grown continually; and in the lack of any alternative crops, a respite from grain meant simply a bare field.

Manifestly, it would usually be better nowadays to substitute some kind of a green crop for the bare fallow. The poorer the land, the greater the need of the green crop; for it might then be ploughed under as manure, or, in default of labor to do that, it might be left to rot upon the surface of the ground; or it might be mown and fed to cattle upon the ground, or be pastured outright. In most cases, however, it will not be necessary thus to sacrifice the green crop; for the latter not only feeds upon the land in a different way from grain, and does not exhaust it like grain, but in one sense it actually tends to refresh the soil, and to make it fit for producing a new crop of grain.

Bare Fallows may improve Tilth.

Before the use of steam ploughs, it was urged by some European writers, that on certain stiff, strong clays occasional bare fallows are wellnigh essential in order that the land may be kept in good condition. But it might well have been asked, even before the steam plough solved the problem, whether some system of cropping could not have been devised for this case, which by shielding the land from injudicious cultivation would have obviated the need of fallowing it. Draining, liming, and an appropriate use of manures, might naturally help to this end. From facts which have been set forth, under the head of Tillage, relating to the danger of puddling clays by improperly working them, it seems probable that the purpose of the fallows in the case now in question was merely to reform the tilth of the land.

Other writers have justly upheld the dictum, that it is much better to have bare fallows occasionally than it would be to continue to grow crops incessantly, in case there was not enough manure at one's disposal to keep the land in a proper state of fermentation; for, by the excessive cropping, poor land would speedily be "run out," i. e. it would become hard, "sour," and "out of condition." In short, there would result a state of affairs not easily to be explained in our present ignorance of the more delicate chemistry or mycology of the soil, but sufficiently well known to practical men as a danger to be avoided. Indeed, if the cropping were pushed too far, the final barrenness of the land induced by the scourging might perhaps necessitate a period of rest much longer than the aggregate of all the bare fallows which, if judiciously interpolated, could have saved the soil from any extreme exhaustion. Excepting the clover rotation, which would be esteemed everywhere were it not for the circumstance that clover is apt to be an uncertain crop, it was recognized long ago in some parts of Europe that more grain can be got, generally speaking, by resorting to systems of rotation which include bare fallows, than by interpolating such green or fallow crops as peas, beans, or vetches. In some localities, it is held that the merit of this class of rotations is not necessarily that a larger yield of the cereal grains can be got by means of them in a given term of years, but that they produce a larger amount of useful products of all kinds, and in the aggregate, without much diminution of the yield of grain. More manure can be got from them also.

Fallow Fields apt to be gullied by Rain.

In all countries that are not actually moist, there is one fundamental objection to the leaving of land bare, especially if it be frequently tilled, in that rains wash away the soil bodily, and winds blow it away. It is by causing such waste as this that careless systems of agriculture tend to destroy a country, and it is by preventing it that forests and prairies preserve the fertility of the land.

Probably there are but three considerations, other than those relating to the prices of labor and land, that can really justify bare fallows; viz. the opportunity afforded to accumulate a store of nitrates in the land for the coming crop; to clear foul land from some kinds of weeds; and the fact that in dry climates fallow land is less likely to suffer from drought in the autumn, at the time for sowing grain, than land from which moisture has been taken all summer by a leafy green crop. In any event, the absence of any crop to hinder the sowing of winter grain as early as may seem fit is clearly an advantage, in that time enough may be allowed for the crop to get well established during the autumn months, and fitted to withstand the severe weather of winter. But early sowing would be impracticable upon land from which a leafy green crop had pumped out the water so thoroughly that not enough moisture was left to permit the seed grain to germinate.

Leafy Crops dry out the Soil.

It has sometimes been thought by practical men, in cases where winter grain has failed to grow well upon land from which a leafy crop, like vetches, had just been taken, that the real trouble may have been that the vetches had dried off the soil too completely, and several scientific writers have insisted that this point is well taken.

The argument is, that the amount of water evaporated by growing plants is so enormous, that a real justification for bare fallows in dry climates is to be found in the fact that a crop of clover or of peas might pump land so nearly dry that not enough water to start a wheat crop would be left in it, while there might have been an ample supply of water in early autumn in that same land, provided nothing had been allowed to grow upon it.

Vogel found that, while the air over a fallow field contained 100 parts of moisture, the air over a field of lucern in blossom contained 125 parts, and that over a meadow of tall grass contained 150 parts. Wilhelm, who has made many experiments to test the influence of tillage and the growth of vegetation upon the amount of moisture in the soil, has obtained results such as the following. He examined, even in late winter, soils from fields on which different kinds of crops had been grown during the previous year, and in a deep loam, rich in humus, he found the following percentage amounts of moisture.

At a Depth of Feet.	In the fresh Earth.		Calculated on dry Earth.	
	Maize Field.	Lucern Field.	Maize Field.	Lucern Field.
½	22.2	17.7	28.5	21.4
1½	16.9	13.2	20.3	15.2
2½	16.4	12.2	19.7	13.9

In a marly, sandy loam, overlying pure moist sand, he found,—

At a Depth of Feet.	In the fresh Earth.		Calculated on dry Earth.	
	Wheat Field.	Beet Field.	Wheat Field.	Beet Field.
½	18.84	16.92	23.22	20.37
1½	20.81	18.01	26.28	21.96
2½	24.26	21.61	32.03	27.57

In both cases, the fields which had been longest covered with growing crops (lucern and beets) contained less moisture than the others. It will be noticed also how the deep-rooted, free-growing lucern sapped the subsoil.

In a year when abundant rains had fallen in August and the first half of September, he contrasted, on October 29, the soils of two contiguous fields which had carried barley and sugar beets respectively. His results were as follows:—

BARLEY FIELD.

Depth and Kind of Soil.	Amount of Water		Water-holding Power of the dry Soil, for Water at 61° F.	The fresh Soil contained % of all the Water it could have held.
	In 100 Parts of the Soil.	For each 100 Parts of dry Soil.		
In ½ ft. loamy marl	14.89	17.60	51.58	34.12
In 1½ ft. loamy, sandy marl . .	18.13	22.15	58.67	73.75
In 2½ ft. sand	3.51	3.64	36.65	9.93

BEET FIELD.

In ½ ft. loamy marl	14.50	16.97	63.69	26.64
In 1½ ft. loamy, sandy marl . .	8.82	9.86	56.11	17.25
In 2½ ft. loamy, sandy marl . .	13.88	16.13	51.99	31.02

Here again the influence of the beets upon the second layer of soil is clearly marked, and it is evident enough that, under less favorable conditions, this crop might deprive the land of water so completely that the success of grain sown after it would be endangered.

At another time Wilhelm divided a field, on which esparcet had been growing for three years, into five plots, as follows: —

No. I. remained covered with the esparcet.

Nos. II. and III. were spaded in April, No. III. being spaded deeper than No. II.

No. IV. was spaded like No. III., and was sown with buckwheat early in August.

No. V. was sown with meslin (oats and vetches) in the middle of April.

Samples of earth were taken from three separate depths for comparison, viz.

From 0.158 metre, say	6¼	inches.
" 0.474 " "	18⅝	"
" 0.790 " "	31	"

The quantity of water in the various earths, in grams, was as follows: —

I. ESPARCET PLOT.

2 April.	5 May.	2 June.	2 July.	5 Aug.	7 Oct.
44.10	33.01	34.78	28.22	29.44	16.71
28.78	27.46	28.30	21.63	16.95	18.66
25.69	27.53	25.18	24.79	20.01	21.51

II. BARE AND LEAST MELLOW PLOT.

2 April.	5 May.	2 June.	2 July.	5 Aug.	7 Oct.
			24.71	28.82	23.27
			22.72	20.34	19.64
			26.43	25.11	23.95

III. BARE BUT MELLOW PLOT.

2 April.	5 May.	2 June.	2 July.	5 Aug.	7 Oct.
	41.28	42.32	30.80		
	26.59	27.45	26.84		
	28.13	26.42	26.30		

IV. BUCKWHEAT PLOT.[1]

5 Aug.	7 Oct.
43.13	25.91
27.82	21.20
27.40	24.15

V. MESLIN PLOT.

2 July.[2]	5 Aug.[3]	7 Oct.[3]
17.16	27.68	22.98
16.73	17.01	16.21
19.52	20.35	19.64

[1] No. IV. was treated precisely like No. III. until the buckwheat was sown.

[2] Just before mowing.

[3] Stubble ground.

The differences between the upper and second layers in the different months depend in part upon varying rainfalls. Thus, the rainfall in the separate months from April to September was: April, 49.76 millimetres; May, 83.24; June, 59.78; July, 98.89; August, 48.52; and September, 32.66.

As compared with some of the others, the esparcet plot No. I. pumped out water from the lower layer of soil incessantly during the summer months.

The bare and comparatively firm earth of plot No. II. evaporated a great deal of moisture from the surface, and from the second layer also when the times were dry. But it was on plot No. V. that some of the most remarkable results of all were noticed. The meslin grew luxuriantly, and it took a great deal of moisture out from the earth; notably from the middle layer, though both the surface soil and the third layer supplied no small quantity. Such a result as this certainly goes far to prove the correctness of the view that winter grain is apt to fail when sown after a thirsty crop; and it supports the inference that the old prejudice in favor of bare fallows may really have depended in many cases upon the need of moisture, and on that account have been more worthy of respect than some modern writers have been willing to allow.

The large proportion of water found in the buckwheat plot is noted by Wilhelm as remarkable. The experiments in this case were repeated several times, in order to make sure of the accuracy of the results. Taken in connection with the familiar fact that buckwheat succeeds well upon light soils as a stubble crop, i. e. in the driest portion of the year, they suggested to him the thought that buckwheat may perhaps need comparatively little water. But the methodical experiments of Hellriegel count against this idea, for it was found that buckwheat really transpires as much water as other kinds of plants.

It is hardly conceivable that the two-course rotation can have been established for the sake of killing weeds, though it is not unlikely that it may have been esteemed both for supplying nitrates and as a safeguard against drought.

Green Crops shade the Surface Soil.

In apparent opposition to what has been said above, as to the removal of water from the soil by crops, it is often urged that green crops do good by shading the ground; that they mulch it, as it were; and there is something of truth in this idea, in so far as the surface soil is concerned. Indeed, evidences of moisture on the surface of the soil, beneath leafy crops, such as beets and rutabagas, are so often to be seen, that it is easy to lose sight of the drain upon the moisture a little lower down which such crops may occasion. The surface soil may be visibly moist, or covered perhaps with fresh moist casts of earth-worms, at a time when bare land is rather dry, and a considerable effort is required in order to grasp the conception that the soil below the surface of the beet field is less moist than would be well.

Misled by these appearances, some persons have even argued that weeds, by shading land, may prevent it from becoming dry. But this idea must be accepted with many qualifications. To refute it, it would only be necessary to examine in dry weather, at a depth of a few inches from the surface, a bare soil that had been hoed recently, and to compare the amount of moisture found there with that contained in similar soil at an equal depth near the roots of a thick growth of weeds. An astonishing difference would be perceived at once. Indeed, on merely pulling up a tall weed in dry weather, the earth attached to its roots will often be seen to be extremely dry.

Nevertheless, the mulching effect of a green crop is valuable on several accounts, and it is a maxim of practical experience, that poor land in high, dry situations may get out of condition more rapidly when left to itself than it would if it were kept covered with vegetation. According to Hohenstein, "when the woods are destroyed in warm and hot countries, the entire atmosphere is changed. The soil becomes hard, and its aspect arid, and the country does indeed look as if it had been worked out and exhausted for all eternity."

In the same sense, it is argued that a sparse growth of spindling plants is not so good for dry land as a dense covering of some leafy crop would be. This remark applies particularly to the class of soils known as light or open, and has less significance in respect to rich loams, or to soils that are tenacious, moist, and compact.

There is manifestly a certain analogy between land shaded by a crop and that shaded by a forest. The same coolness and moisture is found at the surface of the ground in both instances, though in very different degrees, and the action of the roots upon the lower layers of soil is strikingly similar in the two cases. The shading of the land by the green crop, the hindrance which the plants give to the beating action of rain upon the soil, and the dripping of dew, as well as the exhalation of moisture from the leaves of the plants, are all good for the surface soil; and where the surface of the land is kept open, the layers next below will have better opportunity to profit from the access of air and rain than if the upper crust were baked hard.

It is not difficult to understand how it is that with some kinds of crops, such as lucern, for example, more moisture may actually be found in the soil near the surface of the ground than in the lower layers, where the roots are in full action. The excess of moisture in the upper layers of soil is explained by the fact, that at the surface the soil is exposed both by day and by night to the moisture which the leaves of the plants exhale, and that during the night there is an enormous deposition of dew upon the leaves, much of which trickles down to the ground and is held there. Not only is there more dew to fall in the moist air over the leafy plants than there is in the air over a bare fallow, but, since the radiation of heat from the leaf-covered land is greater than from the bare land, dew begins to fall earlier in the evening upon the leaves.

It is noteworthy, however, that the physical forms of different plants, i. e. the manner in which their leaves join the stalks, have a marked influence upon the amount of dew which is shed from the leaves upon the soil. Thus, beets and rutabagas and Indian corn freely shed the dew which is deposited upon them. Much of it trickles down their leaves and stalks to the ground without hindrance. But potatoes, on the other hand, appear not to shed dew so easily; and it will oftener than not be noticed that the earth beneath potato vines seems to be dry.

Moreover, the mere evaporation of water from the surface soil under the leafy plants is less than the evaporation from bare land, since the shaded land is protected from the sun and kept comparatively cool. On the 5th of May, between 3 and 4 P. M., the mean daily temperature of the air of the locality being about 21° C. (= 70° F.), Wilhelm found differences of 13° and 16° C. in the air above a bare field and that above fields of lucern and esparcet in the immediate neighborhood. That is to say, the air over the bare land was 23° F. hotter than that lying over one of the clover fields, and 29° F. hotter than that lying over the other. Moreover, the layer of air that rests upon the soil will naturally be moister where a crop is growing than on bare land, because of exhalation from the leaves, and this circumstance will hinder evaporation from the surface soil. Indeed, it may sometimes happen, as was said, that the soil may absorb from the air a small part of this moisture. Evaporation is lessened also by the fact that the wind has less ready access to the shaded land than to that which is bare.

As has been explained in another connection, the moistened and shaded surface soil must be specially favorable for nitrification, and to this fact probably more than to any other one circumstance should be referred the idea of practical men, that it is well to grow leafy and non-leafy crops in alternation with one another.

Green Crops bring Fertilizers to the Surface.

One other point remains to be considered as bearing upon the practice of growing fallow crops, instead of leaving the land bare, viz. that the capillary flow of water through the land from below upward will necessarily be stronger when plants are growing upon the soil than when the surface is bare. But the stronger the capillary flow, the more soluble matters will be moved from the subsoil towards the surface. Hence, one great merit of clover in a rotation doubtless depends upon its keeping up a constant circulation of moisture in the soil from below upward, whereby large quantities of ash ingredients which the water held dissolved are brought nearer to the surface than they were before, and are left in a position where future crops can profit by them.

It is understood, of course, that all moisture exhaled by the leaves of plants was previously pumped into those plants out of the soil by the roots, and that a capillary movement of water in the soil towards the roots is immediately excited and maintained when the water previously in contact with the roots is thus removed. But this capillary water as it flows towards the roots necessarily brings thither everything which it holds in solution. The clover or other crop consumes what it needs of these transported matters, but there is always a large surplus of them over and above what can be used by the clover, and this surplus remains in the soil for the benefit of succeeding crops.

In a dry, hot climate like our own, the effects due to the transpiration of water from the leaves of plants will naturally be specially well marked. President Dwight of Yale College long ago noticed the peculiar influence of the northwest winds of New England as bearing upon this matter. He was assured by farmers who cultivated tobacco, that the leaves of this plant are perceptibly thicker and heavier after a northwest wind has blown for two or three days than they are at any other time, and that such a season is considered the best for cutting the crop. When grass is mown at such a season, it is noticed that the scythes become covered with the juice, which is then thick and viscid. This "gum" adheres so tenaciously to the metal, that the whetstone has to be used continually, not to give the steel an edge, but to remove the glutinous matter. Hence, conversely, the advantage of mowing grass very early in the morning when dew is upon it.

Legume Rotations.

Beside the rotations in which grass was brought in to refresh the land, other systems based upon the cultivation of legumes have for several hundred years found application in Europe.

As has been said, several Roman writers make mention of this alternation, and it is known that in some districts of England beans were introduced into the three-course system at a very early period, even as early as the time of common fields. In some parts of England it became customary very early to have the arable land of a farm in two great divisions, known as "infield" and "outfield" respectively. The infield was usually smaller than the outfield, and was near the farmyard; it comprised a third or a quarter of all the cultivated land. The size of this division was determined by the amount of dung produced in the farmyard, and it received the whole of it, usually upon the crops of a three-course rotation, viz.: 1. Wheat or barley; 2. Oats or barley; and 3. Beans or peas. But on the outfield the rotation was very different. Sometimes it was grain for two years, followed by two years of fallow field used as pasture; and sometimes there were three fields, each of which was kept three years in grain, and then given over to six years of the poor, fallow, unseeded pasture. Here the grass and the legume rotations overlapped one another. But it was the recognition of the truth that the leguminous plants, such as peas, beans, vetches, and clover, — as well as hoed crops, such as roots or potatoes, — can be grown with success on land that is in no fit condition to sustain a crop of grain, that gave rise to intelligent systems of rotation such as have long prevailed in many parts of Europe.

Here was a decided step in advance; an improvement based on intrinsic merit, and thereby differing essentially from the original three-course system, which depended in good part merely upon physical and social circumstances. Indeed, looking solely from the chemical point of view, the three-course system could hardly be regarded as a true rotation, were it not that in the practice of making barley or oats follow wheat, instead of growing wheat twice in succession, there is a clear recognition of the fundamental idea that different crops act differently upon the soil; and that this idea is the germ of all the improvements which have since been made.

The introduction of beans in the third year, as a preparatory crop for wheat, was undoubtedly a decided improvement upon many stiff soils; and there are several other very old Belgian and English systems which are remarkable for the clearness with which they illustrate the idea that no two crops of like needs should ever succeed one another. Thus, in the county of Kent, there was a two-course system of, 1. grain crops, and 2. part legumes and part turnips, for sheep-food; or of, 1. grain, and 2. beans. The sheep-fold was the source of manure for the wheat. The sheep were fed during spring and summer upon vetches, and during winter upon turnips. Arthur Young mentions an analogous rotation of turnips and barley alternately, with the occasional intervention of clover, on very poor light land in Durham. The turnips were fed off, as in the other case, to folded sheep. Here again are just conceptions of the real significance of rotation. Most of the modern systems are mere extensions of these ideas.

Minor Rules of Rotation.

Several writers have endeavored to systematize the lesser rules of rotation somewhat as follows: —

Such plants as tend particularly to exhaust the soil, like the grain crops, should only be sown when the land is in good heart. They ought not to succeed one another, but should be followed by plants that are less exhausting.

In proportion as a soil is found to be easily exhausted by cropping, plants that are non-exhaustive should be grown more frequently upon it.

It is advantageous to alternate plants that have tap-roots with those which have spreading roots.

No two crops favorable to the growth of weeds should be permitted to succeed each other.

As with weeds, so with insects and fungi. It is essential in many cases to change the crops frequently, to hinder the increase of these pests. There are various insects injurious to grain which would increase to an alarming extent if the land were devoted exclusively to grain crops year after year. But when a crop intervenes on which the insects cannot live, as beans or turnips after wheat or oats, then the whole tribe of grain insects may perish or disappear from the field for want of proper food. The finger-and-toe disease, and the clump-foot, in like manner, prevent the continual cultivation of turnips and cabbages. Farmers and market gardeners in the vicinity of Boston would be glad to grow cabbages year after year upon the same land, but they cannot, because of the disease called clump-foot. So it is with beet roots in Europe. In some localities, nematode worms and other pests prevent the continuous cultivation of the sugar beet.

"*Fallow Crops.*"

For a very long time now, green crops such as those just mentioned have been called "fallow crops," and have been substituted almost everywhere for the old bare fallows. Beside their power of utilizing fresh manure, several of the fallow crops tend to enrich the soil; or, rather, they work against the exhaustion of the soil in several ways. Some of them create a great movement of moisture, by which ash ingredients are brought from afar into the standing-ground of the plants, much in the same way that a forest brings food to the surface. And just as a forest enriches the soil with its leaves, so several of the fallow crops, particularly some of the leguminous plants, leave a large quantity of vegetable matter in the soil. In order to illustrate this point, Boussingault had the roots and stubble of several crops forked out from measured plots, and he determined the weight in kilograms of refuse matters left in and upon a hectare of land by each of the crops mentioned in the table.

	Crop Harvested on a Hectare.		Roots, Stubble, Leaves, Vines, and other Refuse, excluding Straw.		In the Refuse.	
	Fresh or Air-dried.	Dried at 110° C.	Air-dried.	Dried at 110° C.	Nitrogen. Kilos.	Ashes. Kilos.
Clover hay . .	2,500	1,975	2,000	1,547	27.9	194.9
Potatoes . .	12,400	2,988	2,870	687	15.8	122.3
Mangolds . .	14,921	1,820	10,472	1,167	52.5	250.9
Oats	2,031	1,608	912	650	2.6	33.1
Wheat . . .	1,172	1,002	700	518	2.1	36.3

On adding together the figures given above for the five crops plus those for a second crop of wheat which belonged to the rotation, we obtain the following sums total.

Sums of crops	34,196	10,395	17,654	5,087	103.0	673.8
Manure applied	49,086	. . . .	. . . .	10,161	203.2	3,271.9

Whence it appears that the residues left by the crops and buried in the land during the rotation amount to almost half the weight of the manure which was applied at the beginning of the course. The contrast is obscured, however, by the fact that either the beet leaves or the potato vines should be left out from the additions, since only one or the other of these two crops would be grown in the five years' course which Boussingault studied. The two crops were alternative.

With regard to clover, it appears that for every ton of hay harvested 1,600 lb. of roots and stubble are left upon the land, all the weighings being regarded as air-dried products, for the sake of comparison. It is no wonder then that grain crops succeed well after clover, for they must find abundant nourishment in such a mass of decaying organic matter. The clover refuse is necessarily rich in nitrogenized matters, and in ash ingredients also, because the plant is mown while yet green, and before it has reached maturity. In proof of this fertilizing power, Boussingault cites the fact, that wheat taken before clover in the rotation studied by him habitually gives 16 or 17 hectolitres of grain to the hectare, while wheat taken after clover gives 20 to 21 hectolitres.

Several other observers have made detailed observations as to the amounts of stubble left by various crops.[1] The following table by Weiske gives the weight in German pounds (= 1.1 lb. avoirdupois) of residues and fertilizing ingredients left on a Morgen of land (= 0.631 acre), on the average, by the crops enumerated.

There are left in the Ground Pounds of	Rye.	Barley.	Oats.	Wheat.	Red Clover.	Lucern.	Esparcet.
Stubble and roots	3,019	1,142	2,167	1,994	5,116	5,544	3,401
Organic matter .	2,074	924	1,339	1,369	4,015	4,856	2,814
Ash ingredients .	945	218	828	625	1,101	688	587
Nitrogen . . .	37.6	13.2	15.4	13.6	110	78.2	70.8
Potash	18	6	14	11	47	21	25
Phosphoric acid .	15	7	17	7	43	23	17
Lime	42	24	49	44	150	113	67
Magnesia . . .	8	3	7	6	28	14	18

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[1] See Heiden's Düngerlehre, I. 72, and III. 243; also Hellriegel's "Beiträge," p. 166, *et seq.*

There are left in the Ground Pounds of	Crimson Clover.	Serradella.	Buckwheat.	Peas.	Lupines.	Rape.
Stubble and roots .	2,870	1,795	1,259	1,848	2,027	2,557
Organic matter . .	2,311	1,482	992	1,468	1,711	2,200
Ash ingredients . .	559	313	267	385	316	357
Nitrogen	58.7	37.2	27.5	32.5	35.8	34.9
Potash	15	5	5	7	10	27
Phosphoric acid . .	14	11	6	9	8	18
Lime	78	46	46	41	46	71
Magnesia	10	8	4	6	7	8

In Germany, the white lupine as well as the clover crop has been found to be an excellent preparatory crop to precede winter wheat, and the following experiment of Dietrich fully supports this view. He found, in round numbers, 2,000 German lb. of roots and stubble to a Hessian acre (= 0.59 English acre), and in this mass of refuse there was contained some 33 lb. of nitrogen, 922 lb. of carbon (= 3.382 lb. carbonic acid), 41 lb. of lime, 1½ lb. of magnesia, 5 lb. of potash, and 7 lb. of phosphoric acid. Since the lupine is a plant that only succeeds in deep soils, and since from the structure of its roots it is evidently well fitted to take food from the subsoil, it would seem to be especially proper to regard the residues left upon the land by it as contributions from the subsoil to the surface.

The rotation of clover with wheat is practised in some parts of this country; in Ohio, for example, and in some of the grain regions of New York. It will be noticed that clover stubble yields what is to all intents and purposes a green manuring. The case is widely different from that of a crop of flax, for instance, for the flax plant is wellnigh completely removed from the land. And yet it is true that neither the amount of refuse left by clover, nor the quality of this refuse, can wholly explain the merit of this crop as a forerunner of wheat. As may be seen in one of the foregoing tables, the crop of beets examined by Boussingault left much more refuse on the land, and much more nitrogen and ashes in this refuse, than the clover did; yet beets are not esteemed as a crop to precede wheat. On the contrary, in Boussingault's rotation, wheat did not succeed well after beets; not so well, in fact, as it did after potatoes even, which leave a much smaller amount of refuse on the land than beets. After clover, wheat succeeds out of all proportion better than it does after either beets or potatoes.

One reason of this difference will be seen on referring to the experiments of Lawes and Gilbert on page 410 of Volume I., who find that beets and other root crops exhaust the upper layers of the soil

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of available nitrogen much more completely than either beans or clover do. Indeed, beans and clover are remarkably non-exhaustive in this particular respect.

Stress has sometimes been laid also on the different mechanical effects on the soil of the two kinds of crops. Thus, English farmers early in this century, while regarding clover and horse-beans as excellent forerunners of wheat, did not consider potatoes so well fitted for the purpose. For although potatoes, like clover or beans, may be freely dressed with manure, and forced as hard as may be wished, it was thought that the loosening of the soil incident to the cultivation and harvesting of the crop rendered the land less fit for wheat than it was in the other cases. Hence they preferred to sow barley and clover after potatoes, and have the wheat crop succeed the clover.

Leguminous Crops obtain Nitrogen.

There is one point, which has been discussed already at considerable length in another connection, that needs to be insisted upon yet again when considering rotations; viz. that, in order to secure a crop of clover or other leguminous plant on fairly good land, far less nitrogenous manure need be applied than is required to grow a wheat crop. This fact is not a little astonishing, no matter how often it may be regarded, because the leguminous plants are richer in nitrogen than most others, and they really take off from the soil a great deal more nitrogen than wheat, perhaps twice as much on the average. Evidently the leguminous crops are better able to supply themselves with nitrogen from the natural stores in the soil than the grain crops are. It is not impossible, as has been said, that the clover or other legume can feed upon certain nitrogen compounds in the soil which cannot be consumed by grain, just as lupines can take up inorganic matter from powdered rock on which wheat would starve. Or it may be that the plants in question promote in some way the formation of assimilable nitrogen compounds.

The fact that the term of growth of most of the fallow crops is comparatively long, as contrasted with that of grain, is always to be remembered. For the fallow plant not only has a longer time than the grain plant in which to collect food from the soil, but, if, as has been suggested, it does lead to the production of nitrogenous food, it has abundant time in which to accomplish that purpose, and would probably be most active at the moment when its growth is most luxuriant, and there is greatest need of food.

Grain Crops need to be fed with Nitrogen.

The comparatively feeble power of the grain crops to supply themselves with nitrogen is a point that cannot be too strongly insisted upon. Taken in connection with the other fact, that the fallow crops can get nitrogen for themselves from fairly good land, it serves to explain the experience of the English farmers, that, for soils in good condition, assimilable nitrogen compounds are the proper manure for grain crops.

Nitrates and Ammonia not specially useful on Turnips.

It was noticed, however, by Lawes and Gilbert, that, while wheat could be grown upon their land continuously for many years with success without any manure whatsoever, the fields which were sown with turnips came to yield next to nothing after three years' cropping, — a result which I have myself had ample opportunity to corroborate in respect to rutabagas. Then, on applying nitrates, or ammonium salts, their wheat crop was doubled at once, while the turnips were hardly affected at all. On the other hand, an application of superphosphate of lime, while it had little influence on the wheat, brought up their turnip crop at once, and added one new item of evidence to the popular belief that superphosphate is the proper manure for turnips. The question arises in this case, whether the nitrogenous fertilizers offered to the turnips were of the kind really needed. It is, at all events, a plausible inference, that, thanks to the presence of the phosphatic fertilizer, there may have been developed in the soil certain microscopic organisms favorable for the conversion of humus into a form of nitrogenous food fit for the use of turnips, though not fit for the use of wheat.

The practical lesson would seem to be, that for turnips the land should be dressed either with a compost charged with phosphates, or with half or two thirds the usual dose of dung, together with a generous addition of superphosphate.

The fact that the wheat crop stands in special need of nitrogen has important bearings on the theory and practice of rotation. If, for example, a mediocre soil were manured with dung, and cropped with wheat continuously, the fertilizing materials in the dung might be expended to tolerably good purpose during several years, for the nitrogen in the dung would be sufficient to enable the crop to utilize a fair proportion, though not the whole, of the ash ingredients contained in the manure. But by continually repeating upon the the same field the crops of wheat and the dressings of dung, a succession of unconsumed residues of ash ingredients would be left in the land year after year, as long as the experiment was continued.

In order to use up the whole of the ash ingredients, and prevent them from lying idle and useless in the soil, either the manure must be omitted every few years, and some crop be grown which can procure nitrogen for itself from the soil, or enough of some special nitrogenized manure must be added to the land every year in addition to the dung, to enable the wheat to take up the whole of the ash ingredients of the latter.

As bearing upon this point, a set of experiments made by Lawes and Gilbert in three different localities, during periods of from four to eight years, upon soils which had long been under cultivation, may again be cited. It was found that, while the phosphates, sulphates, and carbonates of potash, soda, lime, and magnesia increased the crop of wheat only two or three bushels per acre, as compared with the crop from unmanured soil, a dressing of sulphate of ammonia or chloride of ammonium increased the yield from six to ten bushels.

A French Clover Rotation.

An interesting example of a clover rotation, said to be practised in the vicinity of Nismes, on one of the most fertile tracts in France, is as follows. The course begins with lucern, heavily manured. At the end of four years the lucern is ploughed under, and wheat is grown for four successive years without any manure other than what the lucern sod afforded; then there are two years of sainfoin, followed by two years of wheat, and so back to lucern again. Thus in twelve years six crops of wheat are harvested, and there is only one application of manure. The wheat is of excellent quality, and the average yield is at the rate of 22 bushels to the acre. The manure comes from the town of Nismes, and from sheep.

The example is interesting as showing what can be done in a good climate with a soil naturally fertile, and it illustrates how dependent upon local circumstances all systems of rotation must be. Manifestly no system can be regarded as perfect, excepting perhaps for a single farm or county, at some one special time. They are mere make-shifts, all of them. The burden of proof lies upon each one of the systems, to justify its existence or continuance. The farmer who practises a given system of rotation is bound to show cause why he should not change and improve it.

Fallow Crops are returned to the Land.

One fact of enormous importance is true of most fallow crops; viz. that, besides the refuse they leave in and upon the land, in the form of roots, or leaves, or stubble, a far larger proportion of the crop proper commonly goes back to the land in the form of manure than is the case with the grain crops. The straw of the grain, it is true, is usually returned to the soil in the manure; but, excepting as regards potash, straw has comparatively little fertilizing power, and the grain itself is commonly sold off the farm. A crop of turnips or of clover, on the contrary, is consumed upon the farm, so that the greater part of the nitrogen and the whole of the mineral constituents are returned to the soil.

The Norfolk Rotation.

The somewhat famous system of rotation employed in Norfolk County in England, which at the beginning of this century was known to have been in general use for at least a hundred years, was: 1. Wheat; 2. Barley; 3. Turnips; 4. Barley; 5. Clover; 6. Grass, broken up after the hay harvest and fallowed for wheat. This scheme is specially interesting, as showing how the systems of bare and grass fallows gradually changed to systems of growing green crops upon the fallow fields. The land received a dressing of dung for the wheat and for the turnips, and marl was added occasionally for the barley or the turnips or the wheat. The whole system was made to hinge upon the turnip crop, and the dung of the cattle, to which the turnips were fed. By means of the clover and the grass, fodder for spring and summer feeding was obtained, so that all need of natural pastures was done away with. It is to be remarked that the introduction of clover into Europe during the seventeenth and early in the eighteenth century, and the cultivation of it, naturally brought about very considerable changes in the grass rotations then customary. Indeed, clover soon came to be considered as a kind of grass, and is still regarded as grass by many farmers, even here in America.

The Norfolk system was found to succeed admirably upon the light, shallow, sandy loams of that county, and the maintenance of the course was long made an essential condition in the leases of such land.

The English Four-Course Rotation.

The four-course rotation still much used in England is evidently an offshoot from the Norfolk course. It consists usually of, 1. Turnips, manured; 2. Wheat or barley, with clover seed; 3. Clover, or sometimes beans; 4. Oats, or sometimes wheat. It is said that this course, excellent though it is, cannot be invariably kept up, for sometimes the turnip crop will fail, and sometimes the clover, and whenever either of these mischances happens the regularity of the succession is broken. The old rules of procedure were as follows. In case the turnips failed, the land was left fallow until autumn, when it was sown with wheat and clover, or it was left fallow until next spring and then sown with barley and the clover seed. In case the clover failed, peas were sometimes sown and ploughed under, or sometimes oats were sown in the clover's place and clover in the oats' place. The four years' course has the merit of flexibility, in that it can readily be changed to a five years' course by seeding with a mixture of clover and grass, after the grain, and letting the forage crop stand during two years, instead of one, as just stated.

With regard to the question, what would be the average loss to land worked on the four-course plan of roots, barley, clover (or beans), and wheat, Lawes and Gilbert have assumed, for the sake of the argument, that the products sold off from an acre of land in the four years will be 30 bushels of wheat, 35 bushels of barley, the meat obtained from 10 tons of swedes, and clover equal to 6,000 lb. of clover hay (or 1,500 lb. of bean corn). They admit, furthermore, that the straw of the grain crops, and the dung from the animals that have eaten the roots and clover and beans, are retained upon the farm, and returned each year to the land. Whence it appears that the average annual loss per acre by the sale of grain and meat will be from 4½ to 5 lb. of potash, and from 7 to 8 lb. of phosphoric acid; amounts that may often, if not usually, be made good by disintegration of the soil.

But the common practice in England is to buy oil-cake or the like, which is fed to the animals with the roots, so that the annual loss of potash and phosphoric acid is really much more than made up to the land by thus reinforcing the dung that is put upon it.

A French Five-Course Rotation.

There is a French five-course system of the same general character as the English four-course, viz.: 1. Potatoes, or mangolds, manured; 2. Winter wheat; and 3. Clover sown on the wheat in the spring; 4. Winter wheat on the clover stubble, and turnips as a stolen crop on the wheat stubble; 5. Oats. Here the only manure is given to the roots of the first year. By means of this hoed crop, and by working the fallows on the grain stubble, the land is kept clean, while the clover sod acts as a green manuring.

This course is one of several that were carefully studied by Boussingault many years ago. He found that, starting with potatoes, all the crops of the five years carried off from a hectare of land

8,383	7,173	973	251	1,011
Kilos of Carbon.	Kilos of Oxygen.	Kilos of Hydrogen.	Kilos of Nitrogen.	Kilos of Ash Ingredients.

The amounts of these elements left in the stubble and other refuse of the crops may be judged of in some measure by the statements given on pages 211, 212, of this volume.

The Ash Ingredients of Farm Manure are not well balanced.

In insisting upon a previous page that the amount of nitrogen in farm manure is inadequate fully to balance the ash ingredients, the argument might have been pushed still further, and the kindred fact have been dwelt upon that the several ash ingredients of farm manure are not present in such proportions that they can supply the wants of crops in the best possible way. This fact will appear clearly from the following computations of Heiden, who has contrasted the amounts of potash and phosphoric acid ordinarily contained in farmyard manure with the amounts of these substances which would naturally be carried off from a Prussian Morgen (= 0.631 acre) of land by the crops grown in several modifications of a four-course rotation. Thus, the amounts taken off would be, respectively, in case the course of crops was as follows, —

	Potash. lb.	Phosph. Acid. lb.
1. Wheat	16.40	10.67
2. Oats	10.47	4.59
3. Potatoes	66.41	18.33
4. Hay	39.54	11.32
	132.82	44.81

That is to say, the proportion of potash to phosphoric acid is 2.96 : 1.

In case the crops were, —

1. Wheat	16.90	10.67
2. Barley	17.44	10.65
3. Potatoes	66.41	18.33
4. Hay	39.54	11.32
Potash to phosphoric acid = 2.76 : 1.	140.29	50.97

If the crops were, —

1. Rye	20.03	12.15
2. Oats	10.97	4.59
3. Potatoes	66.41	18.33
4. Hay	39.54	11.32
Potash to phosphoric acid = 2.95 : 1.	136.95	46.39

If the crops were, —

1. Wheat	16.90	10.67
2. Oats	10.97	4.59
3. Mangolds	148.54	25.62
4. Hay	39.54	11.32
Potash to phosphoric acid = 4.13 : 1.	215.95	52.20

If the crops were, —

1. Rye	20.03	12.15
2. Barley	17.44	10.65
3. Mangolds	148.54	25.62
4. Hay	39.54	11.32
Potash to phosphoric acid = 3.78 : 1.	225.55	59.74

Actually, in a 10 years' rotation at Waldau, consisting of bare fallow, winter rape, wheat, peas, rye, potatoes, summer fallow with clover and grass or barley, mown clover, pastured clover, and rye, the crops carried off 263.1 lb. of potash and 120.8 lb. of phosphoric acid (i. e. 2.16 potash to 1 phosphoric acid).

But in 100 pounds of fresh farm-yard manure, Wolff found 0.538 lb. of potash and 0.129 lb. of phosphoric acid. The relation between the two being. 4.17 : 1. And Schmid found in manure from stables of neat cattle in one instance 0.461% potash and 0.126% phosphoric acid (3.66 : 1), and in another instance 0.556% potash and 0.074% phosphoric acid (7.51 : 1). From all of which it appears that cow manure does not contain potash and phosphoric acid in the proportions taken by the crops cited. Hence the liability, on the one hand, of failing to supply a crop with enough of some one kind of food, and the risk, on the other hand, of dosing it with an undue excess of another kind of food.

The figures illustrate (in the cases of potatoes and mangolds, in particular) the importance of rotation considered as a means of putting to profit by means of appropriate crops any constituents of plant-food (potash in this case) which may have accumulated unduly in the soil; and they enforce the lesson that it is often well to reinforce stable manure with small additions of special fertilizers in order to meet the wants of particular crops. This illustration shows, moreover, how vastly important the manure really is in these rotations, in spite of all its defects in respect to proportion, as a means of carrying back to the land great quantities of fertilizing materials, which are regained, as it were, by feeding to cattle the fallow crops and the straw of the grain crops.

It is interesting to note how much more potash than phosphoric acid was taken from the land by the crops here cited, and to speculate as to how long the soil could have continued to supply this potash, or the phosphoric acid either, in case dressings of dung were no longer applied to it. In the case of the farm at Waldau, above cited, it was known that more than enough manure had been employed for many years than was necessary to supply all the ash ingredients taken up by the crops.

Modern Rotations.

Most of the modern systems of rotation in connection with high farming depend, like the systems last alluded to, upon the alternation of straw crops and leaf crops, or, as the old terms were, "white crops" and "brown crops," to the exclusion of pasture land. They are remarkable chiefly because of their elasticity or capacity of admitting a great variety of crops. The farmer is thus left comparatively free to choose whether he will grow more or less of any one of his crops in a given year, according to the indications of the market. Thanks to better systems of tillage and to the use of fertilizing materials brought from without, courses of rotation as they improve tend more and more to free the farmer from rigid bonds, and to bring him back to no system other than that dictated by the prices of produce and of fertilizers in the markets of the world. In making this statement, it is not meant to imply that the idea of rotation will ever be given up, for there can be no doubt about the importance of attending to it. But it is certain that the old notion of adhering inflexibly to given courses of crops through terms of years has lost much of its former significance.

One modern improvement is the very frequent infringement upon the old plan of putting the whole of the manure allotted to a rotation on one crop. The artificial fertilizers enable the farmer to supplement his supplies of dung so easily, that it is now thought to be best to dress the fields frequently, even if not very heavily at any one time. It is recognized also that some crops profit more from dung than others, which will do well with the chemical fertilizers either used by themselves or as additions to a modicum of dung.

It is said that in England potatoes are seldom or never grown without a dressing of dung, and that mangolds and beans are only rarely grown with artificial fertilizers alone. Farmyard manure is there used for all these crops at the rate of 16 to 20 tons to the acre, supplemented usually with 2 or 3, or even 5 cwt. of artificial fertilizers. Even for turnips a common plan is to apply 10 or 11 tons of manure together with a strong dose of superphosphate, as has been already stated.

Circumstances that control Rotations.

Naturally there have always been, and there always will be, various circumstances and conditions, beside those already mentioned, which exert no small amount of influence on the practice of rotation. For instance, either the soil of a farm or the climate of a farm may determine absolutely what kinds of crops shall be grown there, and what kinds of rotations shall be practised. The light soils of Norfolk County were favorable for the turnip husbandry, as has been said, and, in general, light soils in England have been devoted to the growth of barley, turnips, peas, and clover; while on clayey soils the tendency has been to grow wheat, beans, mangolds, and cabbages; and on peaty soils, oats, carrots, and rape. The climate of any mountainous or elevated district will naturally favor grass and oats or rye, rather than maize or the other grains.

In England it has been noticed that the comparatively dry climate of the southern and southeastern parts of the island has led to the cultivation of wheat, barley, and beans, rather than to that of roots and green crops; and, on the other hand, the moist summers of the West of England and Ireland are excellent for grass, oats, turnips, and rape, though not favorable for wheat, barley, peas, and beans.

The luxuriance of foliage at the South of Ireland fills New Englanders with amazement. Sweet-pea vines, for example, are said to grow there to at least three times the size of ours. Moreover, the mild winters of Ireland and the west coast of England have been found to be specially favorable for the growth of early spring forage, such as rye and vetches, and for some kinds of early vegetables. But differences such as these, as regards the relative amounts of grain and forage produced on a farm, will naturally lead to the keeping of different kinds and amounts of live stock; and so to the production of different amounts of manure, and to unlike arrangements both as regards the amount of labor employed and the kinds and order of the rotations.

Catch Crops, or Stolen Crops.

The influence of climate is seen very conspicuously in respect to the so-called "catch crops," or "stolen crops," which are grown in many localities during the latter part of summer on fields where a grain crop has just been harvested, and where a spring-sown crop is to be grown next year. Stubble turnips have long been grown in this way, as in the French rotation mentioned on page 217. White mustard to be mown green for forage is commended by some English writers as an excellent catch crop in many localities. Sown after wheat or oats, at the middle of August, it is said to be ready to be cut (in England) about the middle of October. In mild climates, rape sown in August or September is ready to be cut for fodder in November. But it is essential to success in all such cases that the season shall be tolerably long, and the arrangements such that the catch crop shall not interfere in any way with the crop that is to succeed it. The growing of several successive crops in a single season is seen at its best on farms devoted to market-gardening, where the system has been greatly developed. Several crops have sometimes been taken in a single year in New England, on farms where cows are soiled. For example, after winter rye has been mown for forage in May, fodder corn or Hungarian grass is sown; and after this crop has been mown, turnips may be sown, or barley, to be mown green. But where matters are pressed in this way, no one of the crops can be expected to give a very heavy yield. The power which farmers have nowadays of buying artificial fertilizers makes it easier to grow catch crops than it was formerly. It is easier too to interpolate a crop in a rotation than it once was.

A good example of an interpolated crop is seen in the case of rapeseed, as grown by the Saxon farmers some years since, before petroleum was exported from Pennsylvania. Rape is a branching plant, somewhat like a turnip or cabbage plant in its second year, which bears a multitude of oily seeds from which lamp-oil is made. An enormous development of the cultivation of rape as a summer crop occurred in Saxony soon after the introduction of guano, and for the following reasons, as set forth by Stoeckhardt. It was found that the rape plant is specially well adapted to be grown as the first crop after a heavy dressing of nitrogenous manure, since, unlike most other crops, it shows very little inclination to lodge, under these conditions. Moreover, it leaves the land in excellent condition for the growth of wheat or rye. But since the term of growth of the rape plant is short, and since its seeds could be sold immediately after harvesting them, the crop afforded the farmer an easy means of getting back the money he had spent for the guano. That is to say, in three months' time after the guano was bought, the farmer had his money back and his land in capital condition for sowing his winter grain. He felt sure withal of getting a good crop of grain, without need of applying any more manure for it.

Quantities of Nitrogen taken off by Crops.

In a lecture delivered a few years since in London, Dr. Gilbert dwelt more fully upon the importance of potassic food for the leguminous crops in a rotation than had been done previously by English writers. Much in the same way, he says, that turnips need to be manured with phosphates, and grain with ammoniacal fertilizers, so the leguminous crops are specially grateful for potash.

Provided we supply them with an abundance of potassic food, and a fair store, of course, of phosphoric acid, lime, etc., the leguminous plants can take up nitrogen from the soil with special ease. Thus, beans grown year after year upon land that received no nitrogenous manure, but only a complex mineral fertilizer, rich in potash, took off 61½ lb. of nitrogen per acre per year during the first twelve years of the experiment, against 48 lb. that were taken off per year during the same period by the bean crops grown upon an unmanured plot. During the next twelve years the potassic manure gave 29½ lb. of nitrogen per year, against 14½ lb. from the unmanured plot. And finally, during the whole period of 24 years, the beans that were manured with potash took off 45½ lb. of nitrogen per year and acre, against 31½ lb. obtained from the unmanured plot. Moreover, the beans manured with potash during 24 years took off more than twice as much nitrogen from the land as was taken by either wheat or barley under like conditions.

When red clover was grown instead of beans, the results were rather less satisfactory, because clover is a ticklish crop, that is very liable to fail; it is a crop that can seldom be grown continuously upon any land, and could not be so grown in the case of these experiments. But there was obtained, nevertheless, a very striking illustration of the well-known fact that the growth and removal of a leguminous crop, rich in nitrogen, is one of the best possible preparations for a grain crop.

After the growth of six grain crops in succession, barley was grown upon one part of the land and red clover upon another part.

The barley took off 37½ lb. of nitrogen to the acre, and the clover 151½ lb. Next year barley was grown upon the entire field, and the barley that grew after barley took off 39 lb. of nitrogen, while the barley that succeeded the clover took off 69.4 lb. of nitrogen; or 30½ lb. more after the removal from the land, in the clover, of 151½ lb. of nitrogen, than after the removal of 37½ lb. in the barley.

Moreover, the land was tested very carefully for nitrogen in a number of places before and after the experiment, and it was found in every instance that there was more nitrogen in the surface soil (9 inches deep) after the clover had grown upon it than there had been before. And this, in spite of the fact that all visible roots and vegetable matters were picked out from the soil before analyzing it. Voelcker has obtained results of a similar character to these.

Dr. Gilbert has studied also the consumption of nitrogen from the soil in an actual four-course rotation of crops; viz. turnips, barley, clover or beans, and wheat. The experiments lasted during seven such courses, i. e. 28 years. One part of the land was unmanured, and the rest got superphosphate of lime once every four years. It was given to the turnips which began the course. Under these conditions, an average of 37 lb. of nitrogen per year and acre was taken off in the crops from the unmanured land, or about twice as much as was taken off from unmanured land on which wheat or barley was grown continually.

From the land that was dressed with superphosphate, the average annual yield of nitrogen was 45¼ lb. per year during the 28 years. The superphosphate increased the yield of nitrogen in the turnips in a striking degree, and in the leguminous crops also, though possibly the sulphate of lime in the superphosphate may have had some influence in this case, by acting to set free potash from silicates in the soil. In some adjacent experiments, where, instead of interpolating a leguminous crop between the barley and the wheat, the land was fallowed, the total yield of nitrogen by the whole series of crops was very much less.

Clover may improve Tilth.

There is still another important advantage to be credited to the clover crop in certain localities, viz. its influence on the texture or tilth of the soil. It has been noticed in some of the Western States, that the continual "cultivation" of Indian corn, i. e. the frequent horse-hoeing of it, has a decidedly hurtful action upon the texture of the land. It is well known that certain silts and loams whose particles are very finely divided had better not be stirred when dry, because the particles fall together and become impacted. But such a soil when covered with clover plants and filled with clover roots may be improved in this respect; and when the clover sod is ploughed under, the admixture of organic matter may work to prevent the "dry puddling," and so bring the land into good condition again.

Maize a Fallow Crop.

In the fact that too frequent cultivation may hurt some kinds of land is seen one reason for growing other crops in rotation with Indian corn, at least on fine loams. In general, it may be said, however, that corn differs widely from the other kinds of grains in respect to its chemical requirements. Indeed, for a hundred years and more maize has been classed among fallow crops in the South of Europe.

Motives of existing Rotations.

The styles of rotation now practised in Europe are very numerous, the courses ranging from 4 to 16 or more years. But they may for the most part be thrown into a few general classes. The farmer may, according to the condition of his land and his distance from market, aim either at a strict alternation of white and green crops, or he may press matters in favor of the white crops, and occasionally grow grain twice, or even several times, in succession upon the same field.

The practice of growing grain twice in succession has increased very much of late years, since the sale of commercial fertilizers has put it in the farmer's power to manure his fields without increasing his stock of cattle. In a recent Report of the Royal Agricultural Society of England on the improvement of agriculture, it is said: "Next to the economy of labor (by machines) may be ranked the increase of produce by the expedient of taking two grain crops in succession where the land is clean and in high condition, and can bear the application of special manure, and where the terms of the farmer's lease permit him to follow a rational system of farming. The four-course system of alternate grain and green crops — wheat, turnips, barley, clover — had two great advantages: first, by alternating restorative and cleansing crops with grain; and secondly, by regular distribution of labor throughout the year. The introduction of machines, and of guano, nitrate of soda, and other ammoniacal and phosphatic manures, has now rendered the farmer comparatively independent of this alternate system of cropping."

Even where wheat succeeds clover, it is said to have become customary in some parts of England to put 10 or 12 tons of farmyard manure on the clover sod before ploughing it. Some farmers prefer to apply the manure before the first cutting of the clover, while others apply it between the first and the second cuttings, and others still put it upon the clover stubble just before proceeding to plough it under. In certain grain-growing districts in this country, it is said that Indian corn, barley, and wheat are sometimes now grown in succession, the corn being well manured, and the wheat dressed lightly with an artificial fertilizer.

Rotation Restrictions in Leases.

Some of the old restrictions in English leases have, with the lapse of time, become peculiarly inappropriate. They were originally imposed on the supposition that the farm was to maintain its own fertility directly, so to say. There was no thought, when the restrictions were formulated, that farms could ever be kept up either by buying concentrated fodders or artificial manures. But nowadays the English farmer is largely dependent on these particular resources, and whenever he happens to be restricted as to what crops he shall grow or sell, he finds himself at a disadvantage.

Some leases stipulate that a tenant shall not grow certain crops except at stated intervals; or that he shall not grow more than a specified number of acres of potatoes, for example, in any one year; or that the land shall be kept down to grass for two or more years; or that two grain crops shall never be grown in succession; or that neither hay nor straw nor roots shall ever be sold off the farm.

With regard to the selling of straw, Mr. Lawes has well said, that, while the fertilizing matters in a ton of it may be worth no more than $3, the straw itself may have a market value of $12 or more. Yet the tenant is seldom allowed to sell his straw, although he might buy with the proceeds of it four times as much manure as the straw actually contains in itself.

Beside the modern instances where two or more grain crops are grown in succession, there are others where numerous brown crops are striven for rather than white crops. Examples of this idea are seen where the rotations are arranged to produce as many beet roots as possible, for sugar-making; or potatoes, for starch or for whiskey; or an excess of green fodder, such as lucern or sainfoin, in regions where many cows are kept. A tobacco farmer of the Connecticut Valley has assured me that, for him, beet roots at $6 cash the ton, which was the price offered by sugar manufacturers a few years since, would be a profitable crop, for he could grow them the year after tobacco, when the land is charged with fertilizers. As things stand, he is a good deal put to it for a proper rotation. It does not pay him, he says, to keep cattle; and neither maize nor grain pay any money profit. His land is a bottom-land on a brook; it is a fine loam, the surface being some 15 or 20 feet from the groundwater. For the sake of illustration, three examples of rotations from modern practice are here given. The first is an English eight years' course.

1. Clover.
2. Wheat.
3. Turnips.
4. Oats.
5. Beans, peas, or vetches.
6. Wheat.
7. Mangolds.
8. Barley, sown with clover.

Such a rotation as this admits of a great variety of dispositions in the arrangement of the crops, and provides for long periods between the recurrence of the same crops on the same land. Both turnips and clover, for example, would be more likely to succeed when thus kept apart, than if the four years' course were persisted in.

The second example is from a Belgian farm. It runs as follows:—

1. Potatoes, heavily dunged.
2. Wheat, lightly dunged and some liquid manure.
3. Flax, medium dressing of dung and some liquid manure.
4. Clover, with wood ashes.
5. Rye, heavily dunged and some liquid manure.
6. Oats, with some liquid manure.
7. Buckwheat.

The third example is from a Saxon farm. It runs:—

1. Rape, heavily dunged and guanoed also.
2. Wheat.
3. Potatoes, half dunged.
4. Oats, some guano.
5. Clover, pigeon dung.
6. Rye, heavily dunged.
7. Rape, guano.
8. Wheat.
9. Potatoes, half dunged.
10. Oats, guano.
11. Peas, heavily dunged.
12. Rye.
13. Clover, pigeon dung.
14. Wheat, heavily dunged.
15. Beets, heavily dunged.
16. Barley.
17. Rye, half dunged and guanoed.
18. Clover, pigeon dung.

Probably there was a good supply of potash in this Saxon soil. The significance of the pigeon dung was probably to promote fermentation and nitrification. Doubtless it made the clover run to leaf.

Rotations depend on divers Considerations.

Although it is eminently proper to call attention, as has been done in these chapters, to the chemical principles which are involved in one or another of the various systems of rotation, it should be insisted none the less that the student must take care not to lose sight of numerous other considerations which are of equal, or even greater importance. An attempt has already been made to show how the three-course rotation was a natural outgrowth of certain social conditions. But a somewhat similar remark will apply as well to every other kind of rotation, and indeed to every known system of husbandry, from the brush-burning of the pioneer to the garden culture of Belgium or China.

Systems of rotation — like most other things in this world — have their origin in, and are maintained by, the circumstances which surround them. Every one of the existing systems has been developed by force of local circumstances, and the student must consequently be careful not to attach too much importance to the theory of any one system, or to undervalue the merit of another.

Climate, distance from market, the cost of labor, the ease or difficulty with which manure (or forage) can be procured, the general character of the soil of the district, as well as the amount of capital under the control of the inhabitants, are circumstances any one of which may determine the character of the rotations there habitually practised.

So, too, when the cultivation of one or another crop, or set of crops, has once become habitual in a region, this custom tends to persist, and to exclude other crops and other methods of cultivation. Thus, the cultivation of flax in certain countries, and that of hops or of rape-seed in others, have established claims analogous to those of any other vested interest. Among other incidents, many expert manipulators of the products have been bred, and the modes of preparing and disposing of the crops have become familiar to everybody.

In this country, Indian corn has thus acquired distinct rights of precedence. To say nothing as to any superiority inherent in this crop, the familiarity of our people with the cultivation and use of corn must unquestionably hinder them from trying to grow turnips or other roots as cattle food. So, too, when the time comes for sugar to be produced in the Northern United States, it is to be presumed that sorghum will be grown to this end rather than the sugar beet, simply because the manner of growing sorghum is very much akin to the method of growing maize, with which every one is familiar.

With regard to the influence of capital on the practice of rotation, it is noteworthy that, while a certain amount of it is wellnigh essential for the methodical practice of any course other than an extremely simple one, neither the poor man nor the rich man (working on a very fertile soil) will much trouble himself about the doctrine of extreme regularity. The rigid courses are in fact commonly practised by forehanded or well-to-do people, situated on fairly good land, and possessing cattle enough to yield a proper supply of dung, as well as power to hire an adequate number of laborers. But on land subjected to extremely high cultivation by men rich enough to manage it properly, a rigid system of rotation would be as much out of place as complex courses on very poor land. Excepting as a means of avoiding insects or fungi, rotation has in general very little significance for the market gardener, for example, who buys and applies manure without stint to rich loams abundantly supplied with water.

A rather curious rotation of grass, pulse, and grain is said to occur on the French island Noirmoutiers, the soil of which consists of marsh land, rich in humus, that was reclaimed long ago from the sea. The practice there is, to manure with nothing but sea-weeds and the ashes of dung. As the story goes, the rotation is, —

1–5. Grass, without manure, mown for hay. The yield is light, viz. 2,000–3,000 kilos of hay to the hectare.
6. Beans.
7–10. Wheat, manured with 30,000 kilos sea manure to the hectare.
11. Beans, without sea manure.
12–15. Wheat with sea manure, and so back to grass.

The account is manifestly incomplete, in that it fails to tell where the dung-ashes are applied. Perhaps they are put upon the beans, possibly on the grass.

Preparatory Crops.

It may be added to what has been said already, that the influence of one kind of crop in preparing the ground for another kind is a point much insisted upon by practical men. There is no doubt as to the validity of the fact, and, in seeking to account for it, the chief difficulty lies in the embarrassment which arises from a multiplicity of plausible explanations. For example, several of the leguminous crops are known to be excellent forerunners of grain; and it is said of clover, that it shades the ground and moistens its surface, and so probably permits the growth of the ferment which causes nitrification; that, during its long life, it brings up much food from the lower layers of the soil; that it leaves a great mass of useful stubble, and so constitutes a green manuring; that it is eaten upon the farm, etc.

But how is it with beans? Here is an annual leguminous crop which does not shade the ground much, does not leave any stubble to speak of, and is not necessarily eaten upon the farm, and yet it is an excellent crop to precede grain. One ready answer in this case is, that the experiments of Dietrich have shown that bean roots corrode the soil, as it were, and leave it in a state fit for the grain roots to feed upon. The fact of the matter is, doubtless, that several of these causes combine in the case of the clover. It is because of its acting in several ways that clover is superior to beans as a forerunner of wheat.

So, too, the growth of meslin (mixed crops, such as oats and peas) may depend either on the corroding action of roots, on shade, or on the bringing up of food from below by one of the plants. It is said that these mixed crops often succeed well where a simple grain crop would fail. To influences such as these may be attributed also the fact, that many kinds of crops are accompanied by their own peculiar weeds. Indeed, it might fairly be argued from the success of meslin, that weeds are not necessarily hurtful to crops in all cases. Certain crops, under favorable circumstances, may perhaps be perfectly well able to bear the presence of some kinds of weeds.

It is interesting to observe, that the term of growth of a given plant may be of paramount influence in determining the particular position which this plant, or perhaps another, shall occupy in a rotation; and the remark is specially true of cases where, after one crop has been harvested, the land has to be made ready, or worked, with special care for the crop that is to follow. It is essential that the course of crops shall be so ordered that the plants may not interfere with one another. Each one of the crops must be kept out of the others' way. For example, the interpolation of a crop of turnips after potatoes is easier in Massachusetts nowadays than it was formerly, when only late-ripening varieties of the potato were grown. But, from mere lack of time, such interpolation might not conveniently precede rye or grass, unless indeed the grass seeds were sown with the turnips, as has been done occasionally.

Another consideration that sometimes has its influence in determining the order in which crops are grown, is the necessity of thorough tillage on some soils for success with some kinds of plants. Thus, it is often thought best to grow two hoed crops in succession, in order to make the land clean and mellow for the growth of grass or grain.

CHAPTER XIII.

ACTION OF FIRE ON SOILS.

THERE are several distinct operations in agriculture, the efficacy of which depends upon the action of fire. There is the ordinary brush-burning of new countries, the burning of moorland, and the burning of clay; and, most interesting perhaps of all, there is the old system of burning the sods of stiff clay soils, to which the term "paring and burning" is commonly applied.

At least three conceptions are to be distinguished in this matter of the action of fire: first, the mere destruction of masses of wood which encumber the land, as in clearing a forest; secondly, the destruction or alteration of a portion of the humus in peat bogs and moors, and other soils containing too large a proportion of this constituent, in order to ameliorate the soil; and, thirdly, the roasting of a heavy clay, or of some other mineral, for the sake of altering both its texture and its chemical condition or composition.

Clay Burning.

It will be well, first of all, to speak of the action of fire upon clay, since whatever advantages are to be attributed to such action will usually be felt to some extent in brush-burning, as well as in the paring and burning of sods. It is a well-known fact, that raw clay, that is to say, clay in the state in which it is dug from the earth, is not readily acted upon by chemical agents, — not even by the most powerful acids. But it has also long been known by manufacturers of chemicals, that, when the inert, raw clay is exposed for some time to a dull red heat, it undergoes change to such an extent that after the roasting it readily yields its alumina to acids. This property of clay is constantly made use of in the arts, in the manufacture of alum and of sulphate of alumina; and the fact that the clay undergoes chemical changes of so fundamental a character is undoubtedly one of the reasons why the operation of paring and burning has been found to be advantageous in agriculture.

Excepting peat and moorland, it has come to be pretty well understood that the process of burning is properly applicable only to clayey soils, and experience has shown that burning is by no means equally advantageous to all clays. It appears, for that matter, to be most beneficial upon clays that contain a good deal of silicate of potash and some carbonate of lime. It is supposed that in such clays the lime may decompose the alkaline silicate, and liberate some of the potash. All clays, however, without exception, are improved by moderate burning, in so far as their physical properties are changed in such manner that the plasticity of the crude clay is destroyed, and the mass made light and friable. Properly burnt clay falls to fine powder, and has completely lost its old power of becoming sticky and plastic when moistened and stirred. But it is essential that the burning shall be well managed, and that the fire shall not be allowed to get too hot. When clay thus changed by moderate roasting becomes mixed with that which has remained upon the field unburnt, the character of the soil will be greatly improved. It is worthy of study, moreover, whether by virtue of chemical changes induced by roasting many clays may not become better fitted than they were before to absorb from the soil-water, and to fix potash, ammonia, and other useful bases, in a manner analogous to that of the double silicates of alumina and lime which has so frequently been alluded to on previous pages.

In any event, it is important that the clay should be burnt at as low a temperature as possible, both for the sake of the physical changes and for that of the chemical alterations, of whatever name. For in case the heat were allowed to become too high, portions of the clay would cohere into hard lumps, like bricks, that could not again be reduced to powder, and the chemical activity of the burnt clay would again be lost. It is said that the success of the operation of burning may always be judged of by the readiness with which the clay falls to a uniform friable powder.

One way of burning clay is to mix it with brushwood or peat, or soft-coal slack, and to allow the mixture to smoulder for some time in heaps or pits, or even in special kilns or stoves made for this particular purpose. The process is probably at its best when conducted in this way, for there will be no necessity here of destroying much vegetable matter. The clay to be burned will be taken from beneath the surface, — it may even be dug from pits, — and the fuel employed for burning it will be completely under control. The cost of the process, however, must be high, in any event, because much labor is required.

The pits or trenches in which clay is burned may be made some 2 feet deep, 3 feet wide, and 10 to 20 feet long. At first they are filled to the brim with the fuel, i. e. brushwood or peat, or unmerchantable fire-wood, then a layer of dried clay clods is laid on, and gradually, as the fire burns down, more clay and coal slack, or clay and sods, or clay and brushwood, are thrown on; care being taken that a slow smouldering combustion shall be kept up, and that the fire shall not break out through the clay layer. Whenever flame appears at any point, some clay is immediately thrown there to check the fire. But too much clay must not be put upon the heap all at once, lest the fire be extinguished, and enough fuel must be mixed with the clay to insure the continuous slow burning of it. When once the fire is well started, soft-coal slack or fine coke may be used as the fuel, in case they are to be had more cheaply than waste wood or peat; but at the beginning something more readily combustible than coal is needed.

It is said to have been customary, formerly, in some parts of England, to build special stone kilns in which to burn clay and sods; but the expense of carting such bulky materials to and from the kilns has led to their disuse. To avoid this objection, movable stoves or grates have been invented, which can be carried to the places where the clay or sods are. These grates seem to be specially well suited for burning sods taken from headlands, or from the edges of walls and roadsides, or from waste corners of fields. On clayey soils a great deal of roasted earth can be got in this way, since the dried sods serve as fuel for burning the clay that has been dug out from beneath them.

Sometimes, instead of the old stone kilns, the mixtures of clay and sods were burned in kilns built of sods. These kilns were rectangular constructions, 12 or 15 feet long by 8 or 10 feet wide; their walls were 2 feet thick and 3 or 4 feet high. Channels for draughtways, some 4 by 6 inches in the clear, were built of sods from the corners of the kiln to the centre of it, and fuel was piled up at the middle of the kiln and set on fire. When in full combustion, clay, and clay and sods, were gradually thrown upon it in such manner as not to extinguish the fire nor to permit it to break out and burn freely in any one place. The drafts were closed or left open according to the wind and to the rate of combustion. The walls of the kiln were continually built up with clay, so that they should always be some 12 or 15 inches higher than the burning heap, in order to shield the latter from the wind.

Possibly such work as this might sometimes be done, even where labor is so costly as it is in this country. When hassocks are to be burned, for example, such as are taken from bogs in the process of reclamation, or when brushwood has to be burned where land is being cleared, circumstances may occasionally permit the farmer to roast a quantity of clay which he has had dug out for the purpose at times when work was slack.

Paring and Burning.

The only objection to clay burning is the cost of it. But against paring and burning a serious chemical objection may be urged, for in this case much humus is destroyed. The matter burned is no longer a waste material taken from the edges of fields, nor a mere mineral substance (clay) wellnigh free from organic matter, but it is a true soil, more or less rich in humus and the nitrogen compounds which appertain to humus, and of course these things go to utter waste in the process of combustion. As described by Marshall, the operation of paring and burning was as follows: —

"The bushes and other encumbrances upon the surface of the ground having been removed, the sward is inverted with the breast plough, or 'paring spade' as it is termed, in sods about a foot wide and three feet long. Some judgment is requisite to determine the proper thickness of the sods. If they be pared too thick, they are difficult to burn; if too thin, the sward is not effectually destroyed, and the produce of ashes is too small. A rough spongy surface ought to be pared thicker than one which is firm and bare of grass; and a light shallow soil ought to be pared thinner than one which is deep and more tenacious. An inch may be considered as the medium thickness. If the sods are naked and the season moist, they are set on edge to dry; but if they are grassy, and if the season be fine, this labor may be spared."

"The method of burning is invariably in small heaps, a rod or less asunder, according to the quantity of sod. Small heaps are more conveniently burned than large, and the ashes from them are more easily spread. There are various ways of forming the heaps. The bottom is generally made in a round form, about a yard in diameter, with sods set on edge. Some persons lay on the windward side of this bottom a bough of furze, or other kindling, with the brush-end outward, covering it above with the grassiest and driest bits of sod. They then make up the heap in the form of a small haycock, keeping the sods on the inside as hollow as may be, but laying them flat and close on the outside to keep in the heat. Such heaps are set on fire by igniting the kindling. In other cases, the heaps, formed at the bottom as already described, have a chimney carried up at the middle, into which a shovelful of live coals is thrown in order to kindle them."

When the heaps are well on fire, fresh sods are laid on from time to time, until the whole are expended, not more than perhaps one half of the original sods being used in forming the heaps. The fresh sods are laid upon the side where the fire is strongest: they are seldom added until the fire begins to make its appearance on the outer side of the heap. When all the fresh sods have been used up, the partially burnt bits which fall from the heaps are laid upon the top so that they may be reduced to ashes, or at least exposed to the free action of the fire. The ashes are spread as soon as they have cooled sufficiently, and are ploughed in with a shallow furrow. The operation of paring is said to be commonly undertaken as early as possible in the spring, it being evidently a point of importance to have the soil moist enough to permit the paring plough to slip through it easily. The crops most in use upon land that has been pared and burnt are turnips, rape-seed, and wheat, sometimes oats. Probably cabbages would do well also.

Marshall states, that, at the time he wrote (1796), the practice was, in Yorkshire, confined to comparatively few districts, and in those it was applied only to the reduction of old tough sward. He says:—

"Its effect in improving the contexture of strong, cohesive soils has escaped general notice; yet how could art devise an ingredient more likely to give openness and freedom to a closely textured soil than rough, porous, unperishable ashes? [That is to say, burnt clay.] A material of improvement which the soil itself supplies free of cost. The immediate acquisition of manure from the grass and weeds repays the expense of the operation; while the more permanent improvement of the contexture of the soil is obtained without expense. Viewed in this light, sod burning, whatever effects it may have on light porous soils, is in all human probability a cardinal improvement of soils of a close clayey nature."

So too, Young in his "Six Months' Tour," published in 1770, says:—

"Paring and burning is general throughout the North and West of England. Universal observation has proved it to be a most excellent practice, and has also proved that the idea of thinning the staple of the soil by it is false and groundless. Turnips are the crop everywhere sown after it."

Marshall states, on another page, that the invariable method of breaking up old turf upon the Cotswold Hills, in Gloucestershire, was by paring and burning, to be followed by turnips. The practice still obtains in that region, where it was studied not many years ago by Dr. Voelcker, Chemist to the Royal Agricultural Society of England. Voelcker urges, that it is precisely for the turnip crop that the process of paring and burning is specially advantageous, and that there is little risk of the soil's becoming exhausted, since it is sufficiently enriched by the excrements of the sheep to which the turnips are fed off upon the land. With regard to the loss of humus, as bearing on the power of this substance to absorb aqueous vapor, ammonia, or the like, Voelcker says that there is really little or no need of humus on this account upon clay soils, since the clay itself is a powerful absorbent in that very sense. As concerns the cost of paring and burning, when compared with the cost of applying artificial fertilizers, Voelcker remarks merely that the process continues to be practised upon the very best of the Cotswold farms, as it has been practised for many years.

It is hardly to be supposed, he urges, that a practice so fundamental as this could be persisted in for so long a time upon really good farms, the products of which must be disposed of in the face of the competition of other farms, if it were an essentially improper practice. The act of burning not only destroys all weeds and roots of weeds and seeds of weeds, all insects and eggs of insects, all fungi and spores of fungi, and so leaves the land perfectly clean and clear; but, by the very fact that it reduces much organized matter to ashes, it supplies the turnips abundantly with phosphoric acid and potash in an easily accessible and assimilable form. We know already, for that matter, says Voelcker, that turnips profit more than grain crops from an application of phosphatic ashes. It is a matter of experience with the Cotswold farmers, that their turnip crops are larger in proportion as the fields are more thickly beset with weeds before the paring and burning; and, in support of this observation, Voelcker has found that the ashes of thistles and orchard grass, which abound in that region, are peculiarly rich in phosphoric acid. Indeed, the amount of phosphoric acid in these plants is so large, that as much of it is often added to the land by the operation of burning as would be contained in an abundant manuring with bone-meal. According to Voelcker, the advantage lies not only in the fact that the phosphoric acid and the potash are reduced by the burning to a condition in which they can be more quickly taken up by the turnips than they could be from slowly decomposing organic matters, but in the second fact, that the entire surface soil is thoroughly impregnated with the ashes, so that the roots of the turnips are always in contact with their food.

The loosening of potash in clays rich in lime on burning them, has already been alluded to. It is to Voelcker that our knowledge of this fact is due. He roasted, at different temperatures, clays that contained a good deal of carbonate of lime, and observed that appreciable quantities of the clay became soluble in acids, particularly the potash and silica that were contained in the clay. For example, a clay that contained 7.75% of water, 31.38% of carbonate of lime, 58.62% of real clay, and 2.25% of fine sand, gave up 44% of its constituents to acid, including 0.35% of potash; but after roasting this clay very moderately, 48% of it was soluble in the acid, including 0.77% of potash; and after proper roasting, 54% of it was soluble in the acid.

In a clayey soil from Cirencester, he found the following percentage of constituents: —

	Before Burning.	After Burning, in the Red Ashes.
Hygroscopic moisture	5.98	1.18
Organic matter and fixed water	13.22	8.32
Soluble in acids: —		
Alumina and oxide of iron	12.95	13.42
Carbonate of lime	7.58	8.83
Sulphate of lime	0.43	1.15
Carbonate of magnesia	1.41	. . .
Magnesia	. . .	1.76
Phosphoric acid	trace	0.71
Potash	0.52	1.08
Soda	0.12	0.55
Insoluble in acids, chiefly clay	57.09	62.52
Loss	0.70	. . .

In this particular instance, the quantity of burnt soil amounted to about fifteen tons to the acre, which would make the phosphoric acid equal to 225 lb., and the excess of potash to 188 lb. to the acre.

Struckmann also found in a slaty clay 0.78% of potash soluble in acids before the burning, and 1.53% of potash after the burning.

In another instance, Voelcker found these percentages: —

	Unburnt Soil.	Ashes therefrom.
Water	0.93	9.12
Organic matter	10.67	
Soluble in acids: —		
Alumina and oxide of iron	13.40	14.56
Much carbonate of lime, with	23.90	17.17
Sulphate of lime		1.73
Carbonate of magnesia	1.10	. . .
Magnesia	. . .	0.40
Potash	0.38	1.61
Soda	0.13	0.04
Phosphoric acid	trace	1.84
Soluble silica	. . .	8.70
Insoluble in acids, chiefly clay	49.66	44.64

The increase in phosphoric acid probably comes from the destruction of organic matters of which it was a constituent; so long as the organic matters remained intact, acids did not dissolve out the phosphoric acid from them. Other researches of Voelcker on the roasting of mere clays at different temperatures have shown that less phosphoric acid could be dissolved out from the roasted products by acids than from the original clays. It was found, too, that while considerable amounts of potash were made soluble (in acids) by moderate roastings, some of that which had become sol-

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uble in this way passed again into the insoluble state on strongly heating the clay. Whence it appears that it is indispensably necessary to maintain a low temperature during the process of burning.

Field Experiments on Burnt Soils.

From field experiments made in Germany by Struckmann, it appears that both "paring and burning," properly so called, and clay burning, but particularly the latter, have distinct merit. According to this observer, clay burning may undoubtedly be practised with advantage in many cases, even in localities where the cost of burning is high. In the first year of his experiments, neither vetches (cut green) nor flax profited much from the burning; but the crops of rutabagas and cabbages were largely increased, both on the plots that had been pared and burnt, and upon those that were dressed with burnt clay. After the crops had been gathered, and the land had been prepared for wheat, it was noticed that the mechanical condition of the soil was surprisingly good upon the burnt plots. Instead of the old heavy, stiff, cohesive clay, there was found a light, crumbly loam.

After the first year's crops were harvested, the land was laid down to winter wheat, so that in the second year wheat was grown upon all the plots, and it was found, not only that the effects of guano and lime applied in the previous year were specially conspicuous upon the burnt plots and those which had received a dressing of burnt clay, but that guano applied in the second year produced better crops upon the burnt land than upon that which had not been burnt.

Pusey, in England, pared and burnt a very tenacious clay, and grew oats upon it, in contrast with oats on a contiguous unburned field. The crop from the burnt land was 48 bushels to the acre, and that from the unburnt land only 16 bushels. The same land was again burnt, the next year, and sown with wheat. It was then so hard that it could only be pared after it had been wetted with rain. The crop from the burnt land was now 40 bushels to the acre, and that from the unburnt 20 bushels. Manifestly, in the case of a clay like this, the mechanical improvement of the soil due to the dissemination of the nonplastic ashes must be of paramount importance.

Cartwright, experimenting on a cold, adhesive clay, applied 400 bushels of roasted clay to one portion of the land, 100 bushels of wood ashes to another, and nothing to a third portion. He harvested the following crops, respectively, from the different plots.

Plots treated with	Rutabagas. cwt.	Kohlrabi. cwt.	Potatoes. cwt.	Barley. Bushels.
Burnt clay	502	137½	480	36
Wood ashes	472	78½	456	34
Nothing	204	87½	340	24

Mr. Mechi, a London alderman, who not infrequently talked sound sense in spite of occasional vagaries, was strongly in favor of clay burning. He says: "Burned clay ashes are true friends of the farmer on heavy land. They descend gradually into the subsoil beneath the ploughed land, fertilizing it, and rendering it more porous and acceptable to the roots of plants. Twenty years of experience have taught me that nothing pays better than burning stiff brick clays in dry weather. From a state poisonous to plants, the land passes, by burning, into a fruitful condition. Worthless pastures, ploughed lightly and burned, become fruitful and productive fields."

"How remarkable," he exclaims, "is the change produced in stiff clays by burning! Cold, wet, heavy and adhesive, or slippery, according to the weather, they at once become friable, non-adhesive, warm, and dry." And again, speaking of burned earth, he says: "Our stiff, plastic, non-calcareous clay, almost free from vegetable matter, becomes, when burned, real brick-dust, and yet it is a most valuable fertilizer. Twenty years ago I burned an immense quantity with great advantage. Science teaches us the why and the wherefore. It tells us that the hitherto unavailable elements of plant-food locked up in our stiff clays become liberated by the action of fire, and are rendered available for the feeding of our crops. But there is another and a more important advantage. The physical condition of the soil is entirely changed by burning. The bird-lime or putty-like soil, previously almost impervious to air or water, becomes loose and friable, permitting the free circulation of plant roots, and making the land work easier and leave the plough easily. There is no safer investment on stiff clays than burning the sticky, dense, unmanured subsoil. Where fuel is dear, the clay must be dried in the air before burning, and it is of course summer work anyway. One ton of soft-coal dust will burn twenty tons of earth."

Coal Ashes analogous to Burnt Clay.

It is to be noticed that much of what has been said of burnt clay will apply to coal ashes also. Practically, coal ashes have been found to do excellent service on clay soils. They are said to answer a better purpose than sand, because they remain in the clay, and do not sift out into the subsoil so completely as sand will in the course of a few years.

Refractoriness of Clay.

As has been already many times stated, the great trouble with clay soils in their natural unregenerate condition is their plasticity. The clays are commonly "strong" soils, in the sense that they contain a large proportion of plant-food, but they are at the same time "stiff" and "heavy," hard to work, little permeable to moisture, and slow to dry. A clay soil will absorb a great deal of moisture, and will retain it obstinately, and it is easily conceivable that both these qualities may be useful in favorable years. But in wet seasons clay lands remain excessively wet, and any attempt to cultivate them while wet might be fatal, since the instruments of tillage would simply puddle the earth.

On the other hand, in seasons of extreme drought, clay lands become baked so hard that the roots of plants can hardly penetrate them; the land cracks withal, and in that way tears asunder and destroys many roots. So too, in winter, the wet clay "heaves" badly in freezing, and destroys plant roots in that way. Hence the great advantage of draining, and of introducing the rough ashes and burnt clay just now under discussion as a means of altering the relations of the soil to water.

Burning of Moorland.

The burning of peat and moorland, that is to say, of soils surcharged with humus, is even more important as a means of culture than the operations already described, the chief significance of which depends upon the roasting of clay. Moor burning is practised to an enormous extent in many places, particularly in Finland and in several of the Northern provinces of Germany, notably in Hanover, Friesland, Lunenburg, and Oldenburg, and in Holland also. In these regions it is still the usual method of reclaiming peaty soils, and very large tracts of moorland have there been brought into profitable cultivation by means of it. There are many localities, indeed, where no other known system of cultivation could be made profitable under the existing conditions as regards labor and roads. Moor burning has the merit of being a quick method of putting waste land to profit. Thus, a German farmer, Lippe, has written as follows: —

"At the beginning of last year, three and twenty acres of waste peat moor lay before me, where now is to be seen only a field of most luxuriant rye.

"The waste land produced nothing but rushes, wool-grass, and a few spears of sour forage, besides thistles and enormous masses of aquatic mosses. Here and there a miserable bush or a crippled birch was visible, but in most places the spongy soil sank under the feet of whatever trod upon it. Formerly cattle had been permitted to seek a meagre subsistence upon the tract, but they often sank deep into the miry ground, and could only be extricated from the seemingly bottomless slough by means of beams and levers, ropes and windlass, applied at the risk of one's life. But by simply draining and burning the waste land, without applying to it any manure or other ameliorant, it has been converted as if by magic to an exquisitely green field of most vigorous rye."

In a case like this, one great merit of the burning consists in destroying the loose moss and other trash which encumbered the surface of the land.

Moor Burning not necessarily exhaustive.

It has been sometimes objected, that large quantities of valuable peat must be destroyed on burning moorland, and the governments of some of the German states have been solicited to interfere in the matter, and prevent the waste of the national wealth. But in point of fact this objection is not very well founded. It is not ripe peat that is destroyed, — the farmer does not seek to destroy much of it, — but chiefly the crude superficial coating of moss and roots. In the German practice the depth to which this crust is burnt rarely exceeds some 12 or 16 inches, and it has been observed in districts where moor burning has been practised for centuries that the amount of material destroyed is scarcely appreciable.

When left to lie fallow mosses and other vegetation soon cover the land, and fit it to be again burnt in due season. The real objection to moor burning is the cloud of unpleasant smoke which fills the air. There are anti-smoke societies in several of the Northern German cities, which work to instruct, persuade, and coerce the farmers to desist from a practice which at certain seasons greatly annoys the citizens.

The methods employed for moor burning vary somewhat in different localities, but, speaking in general terms, it may be said that the surface of the land is pared at a dry time to a depth which experience has shown to be sufficient; the sods are allowed to dry, being often set on edge to facilitate the drying, and are finally burnt, either as they lie, or in little heaps, without any special care being taken to regulate the rate of combustion. The ashes and carbonized matters are spread and harrowed in immediately.

In the best practice, as where the moor has been drained as a preliminary to the burning, the land once reclaimed in this way is kept in good condition by the use of manures, either natural or artificial, notably by means of guano, superphosphates, bone-meal or bone-ash, lime, and potash salts.

Usually, however, the burnt land, after it has been cropped for a series of years, is left to lie fallow, and to revert to its original condition, while a new parcel of the wild moor is burnt and brought under cultivation.

Effects of Fire on Peat.

Several useful effects are brought about by burning peaty soils: the wild vegetation is destroyed, and its ashes, as well as those of the burnt peat, become available, both as manure properly so called, and as material for improving the mechanical texture of the peat that is left. Besides what is actually burned, a very considerable quantity of the peat is charred. That is to say, it suffers all conceivable degrees of alteration, from being slightly scorched, or even barely heated, up to being burnt to a cinder. But all the peat thus altered goes to change the texture of the soil, and to improve its physical condition, especially as regards its power of absorbing and holding water.

The heat, moreover, distils off and destroys resinous matters, which would cause the dry peat to repel water; and it destroys the acids which make the moorland sour. The burning acts also to promote the solubility of inorganic materials in the peat, just as it acts upon clay to that end, though this point is probably one of but small importance as regards peat. Several of these points have been proved by Stoeckhardt, by a set of experiments in which a lignite-like moor earth was gradually heated. Thus he found:—

In 100 Parts of the Earth.	When Dried at 100° C.	When Roasted 3 Hours, at 200° C.	at 300° C.	After Distinct Glimmering.
Combustible matter	81.70	78.50	72.25	41.30
Ashes	18.30	21.50	27.75	58.70
Inorganic matter, soluble in water	0.47	0.84	0.53	2.58
Organic matter, soluble in water .	1.36	1.25	0.43	0.99
Resin, etc., soluble in alcohol . .	3.55	2.52	1.10	0.87
Lime needed to neutralize the acid	3.75	2.14	0.27	0.17

But gradual and successive stages of heating, such as were here studied, would naturally be found in practice in the peat beneath that actually burnt. Wild in his "Die Niederlände," speaking of moor burning, says that in this system of husbandry it is not the intention to burn the sods to ashes, but only to change them to imperfect charcoal. Moor burning is not a process of combustion properly so called, but a system of carbonizing turf that is thickly beset with heather.

To show how true this assertion is, Wild's description of the method of burning a primeval moor may be quoted. First of all, frequent drainage ditches are cut, and the moor is left to dry out somewhat, a process which often requires several years. The growth of heather and other plants on the surface of the moor is then pared off, usually in autumn, in great flaps, which are left lying inverted beside one another, exposed to wind and sun so that they may dry off during the winter. Next spring, as soon as the moor can be worked upon, usually at the beginning of May, the partially dried sods are set on fire on the under side where the heather is. They burn slowly, without visible flame, but with a very thick smoke, not to ashes, but merely to imperfect charcoal for the most part. It is customary to light the sods between seven and nine o'clock in the morning, when the dew has evaporated, and to extinguish the fire towards evening. Fire is set at the leeward edge of the field, in order that the combustion may proceed with regularity, and be kept under control. The laborers take pains to smother any places where actual flame may break out by throwing damp sods upon the fire. In the course of 48 hours after the burning, buckwheat is sown in the warm ashes, and harrowed in with hand harrows.

Experiments on Burnt Moors.

Some highly instructive field experiments were made several years ago at one of the German experiment stations by Dr. Zacharia. He proposed to test the questions, Is it the destruction of the undue excess of humus that improves a peaty soil when it is burned? Or is it the alteration in the character of the soil as regards its power of absorbing water, or is it the ashes produced, that are specially beneficial? In other words, What is the relative value of each of these several factors, and how does their value compare with that of manures that might be bought and applied to the land? And how does the method of culture by burning compare with other methods of culture?

Three parcels of moorland were staked out and treated as follows. The sod of the first parcel was ploughed under in the autumn; that upon the second parcel was pared and carried away from the land in the autumn also; but the next spring the sod upon the third parcel was pared and burnt in heaps upon the land. Each of the parcels was then subdivided into plots, and the plots upon the burnt land were treated as follows. From Plot "A" the ashes were carefully collected (there were some 9,000 or 10,000 English pounds of them to the acre), and transferred to Plot "C," where they were strewn, together with the ashes proper to "C." But the ashes of Plot "B" were strewn upon that plot. Various manures were applied to the plots of the other parcels of land, and the whole field was finally ploughed and planted with barley, in May. At the middle of August the barley was harvested with the following results in Prussian pounds to the Morgen:—

Plots.	Parcel I. (Sod ploughed under.)		Parcel II. (Sod carried off.)	
	Grain.	Straw, &c.	Grain.	Straw, &c.
(a) No manure	58	165	14	75
(b) 1,000 lb. wood ashes . .	198	375	196	321
(c) 200 lb. bone-meal . . .	219	450	122	334
(d) 100 lb. Peru guano . .	111	439	135	334
(e) 1,000 lb. lime	41	184	35	120
(f) Sand	97	286	31	65

Plots.	Parcel III. (Pared and burnt.)	
	Grain.	Straw, &c.
A. No ashes	378	828
B. Its own ashes	850	1,300
C. Double dose ashes	847	1,552

It appears, 1. that it was better to plough under the sod than to carry it off; 2. that the lime was of no use as regards this first crop; 3. that although the bone-meal and guano and ashes were useful, they were not very useful,—neither of them gave any money profit; 4. that the mere heating of a portion of the soil by the process of burning the sod in heaps, even when the ashes were removed, did twice as much good as the average action of the guano and wood ashes and bone-meal; 5. that this heating of the earth plus the ashes resulting from the paring and burning gave abundant and profitable crops, while the double dose of ashes did little or no good.

It was made plain by these experiments that moor burning was an eminently proper mode of culture for the land upon which the trials were made. It was proved also that the heating of the earth was as important as the production of ashes; indeed, it was of more importance, for the moment the amount of ashes put upon the land was in excess of what the crop needed, it was evident that matters had been carried too far. For the case in hand, the paring of a thin slice of sod would have been better than a thick slice.

Thin Moors not fit for burning.

Per contra, a good deal of evidence has been collected in France which goes to show that in some soils the good effects of moor burning, though plainly manifested at first, are ephemeral, and not to be seen after one or two seasons. The French chemist Malaguti, who lectured at Rennes in the West of France, has much to say about the system as practised in his vicinity. He shows clearly that for those conditions the merit of the process depends, not upon chemical considerations, but upon its cheapness, and upon the fact that it yields a quick return for the labor expended.

It would appear, however, that the French moorlands are very different from the German. The French moors seem to be not the incipient peat-bogs so common in North Germany, but cold shallow soils, like our own springy hillsides, consisting of a thin layer of sod, or rather of hassocks and bushes overlying clay or gravel. Hence the burning of a French moor would seem to be more nearly akin to clay burning, or to the paring and burning of old grass sod, which is probably seldom or never justifiable unless it be connected with a system of turnip-growing and sheep-raising upon stiff clay land.

For the permanent improvement of this kind of moorland, — unless indeed it is based upon clay, — it has been found to be best to turn under the sod and let it rot in the ground, rather than to destroy the nitrogen in the organic matter by means of fire.

Brush Burning.

The burning of logs and brush, when new land is cleared, has evidently, so far as the chemistry of the subject is concerned, much in common with the processes of clay burning and peat burning. Brush burning is practised in all wild countries. It is almost as common to-day in the Scandinavian countries, and in some districts in the interior of Europe, as it is in the Northern United States.

German writers very often give brush burning a place in their lists of the different systems of farming. Indeed, one could hardly find a more concise account of the practice than the following, taken from an account of the agriculture of Bohemia, printed in 1856.

"The brush-burning system of farming, the so-called clearing of land by fire, which consists of a rotation or interchange between woodland and tillage, is practised to a certain extent in the mountainous parts of the country, as well as in some of the more densely wooded sections. It consists in cutting down the wood or the bushes from the tract to be cleared, and burning them upon the land. The ashes are then scattered, the earth broken up, as well as may be, and seeded down once or twice with oats or rye. The ground is then left to cover itself with grass, and finally with bushes and trees."

There are of course a variety of intermediate systems between this crude process that the Bohemian writer describes, and the methods of clearing in which no fire is permitted. Some of our farmers, for example, sow grass-seed with the rye, and often, of course, the land is kept permanently under cultivation instead of being allowed to revert to the condition of forest. But, so far as concerns the chemistry of the matter, these points of detail are wholly immaterial. For the moment, the question at issue is, What effects may such fires have upon the land? Something may be learned as to this point by considering what happens in the cases of clay burning and moor burning as already considered.

In brush burning there is often an almost total destruction of the humus that had accumulated while the land was in wood, and in nine cases out of ten this result may be accounted highly pernicious. It is precisely this woodland humus that is usually the sweetest, mellowest, and best. There is an abundant production of ashes, by means of which the crops of the first and second years are usually well manured, though a good part of the ashes are sometimes swept away bodily from burned land by heavy showers, while some of them are apt to be blown away by wind. When the soil to be cleared contains clay, some of the good effects of clay burning are doubtless produced, and in most instances many rocks and stones are crumbled. Looking at the matter, however, solely from the chemical print of view, it is hard to avoid the conviction that brush burning commonly injures the land. There is little to justify it beside the mechanical necessity of removing wood from the land. Albeit this consideration is one of paramount importance, for wood is a grievous incumbrance upon land in districts where it has no merchantable value. It is to be remembered that, if wood were not combustible, it would be as much in the way upon the land as so many stones of equal magnitude. No ephemeral advantage gained from the ash manuring, or perchance from the roasting of clay in the soil, can compensate for the destruction of the nitrogen in the humus which had accumulated beneath the bushes or trees.

CHAPTER XIV.

IRRIGATION.

If it can be said of any one item of good practice in agriculture more than of another, that it is shamefully neglected in the Atlantic States, it will assuredly be said of irrigation. In spite of all that has been done of late years in California and the adjacent regions, it is still probably true that no other subject relating to agriculture so much needs to be attended to by the American people as this matter of watering the land.

Strange as it may seem at first sight, the question of irrigation is largely a chemical question; and in asserting that the densest ignorance seems to prevail among New England farmers with regard to this branch of husbandry, it is not meant to imply that the people of this section of the country know nothing about the guiding or lifting of water by means of aqueducts and sluices, or by windmills or steam pumps. On the contrary, the history of milling and manufacturing in New England, and of hydraulic mining in California, teaches that there are few people more ready to undertake the management of water than our own, or better able to deal with it.

Water may act as Manure.

It is urged only, that not one farmer in a thousand seems to have any just conception of the fact that by applying water to the land we manure the land by means of matters which the water holds dissolved and invisible. Not only may land be fertilized in this way, but in many cases it may be fertilized adequately for the continual production of remunerative crops. Indeed, it may be said of almost every case where land is skilfully irrigated, that fairly good crops of hay, at least, may be obtained year after year without adding any other manure than that which the water affords.

Some of the experiments made in recent years by the methods of water culture and sand culture teach an important lesson as to the true significance of irrigation. It is easy, for example, to grow tolerably good plants in mere pit-sand which is abundantly watered with brook or river water. Indeed, Boussingault reports that he has seen rich crops of Indian corn harvested upon the plateau of the Andes on sand that was almost moving, but which was abundantly and skilfully irrigated. I have myself grown several kinds of plants, with success, in coal ashes admixed with peat, and freely watered. The familiar fact so often to be observed in domestic horticulture, that cuttings of various plants will grow and even thrive in jars of well-water, goes far to enforce a similar lesson. But there is small need to multiply instances to illustrate a subject which has already been dwelt upon at sufficient length in another connection.

If, as has been shown, plants take in their food from and through the soil-water, it will evidently be good policy to supply water enough to enable them to take up their food to the best possible advantage, under the most favorable conditions. If, as has been shown, large quantities of nitrates and of other useful ingredients run to waste in the waters of brooks and rivers, it will manifestly be well to pour such water back upon the land from which it has soaked out, or, better still, to pour it upon land that stands in special need of nitrates and the other dissolved matters.

Moreover, if it be true, as is seen indeed to be the case every summer in times of plentiful rains, that an abundant and well-distributed supply of water is most favorable for the growth of plants, there can be no question that many farmers would do well to provide a permanent and controllable water supply when this can be done without undue cost. Of course manure may be put upon land that is to be irrigated, as well as upon any other.

Moisture enables Manure to act.

Indeed, it is precisely upon well-watered soils that manure is used with the utmost advantage, since under these conditions the crops can readily gain access to and absorb the fertilizing matters. In many situations a small amount of manure applied to irrigated land will produce results such as could not be obtained by the most generous dressings of dung, if the land had nothing to depend upon but the rain which falls upon it.

Every New England farmer knows that it is in rainy years, and not in years that are dry, that his poor, light soils produce tolerable, or even good crops, and it is precisely upon such soils that abundant crops could be obtained every year by systematic irrigation. It is true enough, as a general rule, that crops suffer less from drought on well-manured land than on land that has been inadequately fertilized; but it is true also, that a small amount of manure upon land abundantly moistened will do far more good than a much larger quantity of manure could do without the moisture.

Light, porous soils, that are not too fine, and particularly gravels and sands, are specially proper for irrigation, for the excess of water can readily drain away from them, and there will be comparatively little risk of puddling such soils at the surface. Clays, on the contrary, are not well adapted for the process, and probably can seldom or never be benefited by it, unless they are provided with tile drains and kept permanently in grass, or are very carefully mulched.

Importance of Water as such.

Water considered merely as water, without reference to the plant-food which is dissolved in it, is an important agent in promoting the growth of plants. Not only the circulation of matters within the plant, and the chemical processes and reactions which occur there, but the very life of the plant, depend upon the presence of an abundance of liquid water. When water is plenty, many plants can use over and over again a given store of ash ingredients. That is to say, even a small store of ash ingredients such as might be present in a seed can be used first in the young shoot, and then in the future leaves, and yet again in the leaves that follow, provided the plant be kept juicy by means of water. This fact is seen often enough in the case of Wandering-Jew plants grown in water, and it may readily be exhibited by sowing nasturtium seeds in pure sand and watering the young plants with rain-water. Several successions of leaves on a long straggling plant can readily be obtained in this way.

Amount of Water needed by Plants.

It may be well, perhaps, at this point to dwell again for a moment on the enormous amounts of water that are needed by cultivated plants. Plants contain a great deal of water to begin with. Analysis shows as much as 95 lb. of water in every 100 lb. of the more succulent fruits and vegetables, such as melons, cucumbers, lettuce, and asparagus, and some 90% in ordinary roots and vegetables; young grass contains 80 to 85%, grain plants when in blossom 75%, and even mature leaves of trees some 60%. Since these proportions of water are found to remain wellnigh constantly the same in healthy plants, even when the external conditions vary considerably, it seems plain that they cannot be accidental, but that they must be essential for the physiological processes which occur within the plant. For that matter, it is easy to see why plants should contain a great deal of water, because nothing can be more evident than that the contents of their cells need to be kept moist. The protoplasm of the active cells has to be kept in a glutinous, half-liquid condition, in order that its functions may be properly performed. In case the contents of the cells should become too consistent through loss of water, the activity of the cells would be diminished, and would wholly cease if all the water were removed. In order to the continuous life and growth of a plant there must be continual movements of matter within it from one cell to another, and from one part of the plant to another, such as could not occur unless the active cells and membranes were kept constantly moist. In general it may be said, that it is only when a plant is properly charged with moisture that it can grow freely. Whenever, from any cause, the supply of water is inadequate, the development of the plant must necessarily be diminished.

When do Plants wilt?

As has been set forth on a previous page, the necessary supply of water comes from the soil, and is kept up by the osmotic pumping action of the roots, while, on the other hand, water is continually expended by exhalation of vapor from the leaves, sometimes in such quantities that a very few hours of hot, dry summer weather would be sufficient to dry out a plant completely if new supplies of moisture were not constantly brought into it to make good the loss.

It is in young plants at the time when leaves are being most freely developed that the need of water and the waste of water are greatest. An extremely interesting illustration of this point is afforded by the grain crop of California. In that region rain enough falls in the winter to supply the plants adequately with moisture during the period of active growth, but by the time of ripening there is no longer water enough left in the soil to enable a growing crop to prosper.

Hellriegel has made numerous experiments to determine, as nearly as might be, how small a quantity of water in the soil is sufficient to keep crops from wilting under ordinary conditions of temperature.

Some of his results, as obtained with garden loam, on different days in June, are given in the following table.

When the Fahr. Temperature at Noon was about		When the Percentage of Water in the Soil was
80°	Lupines began to wilt	13
79°	Lupines did not wilt	14–16
76–82°	Beans began to wilt	10–13
79°	Beans did not wilt	14–15
76°	Clover began to wilt	14
70–80°	Clover did not wilt	13–16
76–80°	Buckwheat began to wilt	10–16
79°	Buckwheat did not wilt	14–16
76–81°	Peas began to wilt	7–13
76–81°	Peas did not wilt	8–14
80°	Barley began to wilt	8½
76–79°	Barley did not wilt	11–15

It appeared that plants differ considerably as to their powers of meeting an exceptionally rapid loss of water by transpiration. Peas and barley, for example, did better in this respect than the other leguminous plants or than buckwheat. But it was evident, for the cases of the plants experimented upon, that, in order to guard against the possibility of wilting, there needed to be a tolerably large amount of moisture in the soil. For the garden loam of the experiments, it may be said that at least 16% of water (about 35% of all the water this earth could hold) would need to be present in hot, dry summer weather in order properly to satisfy the plants. At more moderate temperatures, however, and in air less dry, plants might not suffer much inconvenience even if there were a considerably smaller quantity of moisture in the soil than this; and when the weather is cool and the air very damp, there need hardly be much more water in the soil than what would be held there hygroscopically.

Hellriegel insists that the wilting of a plant does not indicate its first actual sufferings from want of water, but is rather a sign of the beginning of the last stages of endurance. He urges that, whenever a soil has dried out to such an extent that plants can no longer quickly supply themselves from it with water to make good what they have lost by transpiration, the flow of sap within the plants must necessarily become sluggish, and all the movements of food or other constituents from one part of the plant to another must go on more and more slowly and incompletely, until they finally come to a standstill. So long as the drought continues, the proportion of water in the plants will diminish from day to day and from hour to hour, and the efficiency of the organs which move the sap will be more and more impaired, until outward signs of the trouble are manifested by the flabbiness of the leaves; but by this time the plant may have got into a condition most unfavorable for growth, and highly undesirable from the economic point of view.

Hellriegel has constantly observed on the sandy soil of his vicinity (Dahme in Prussia), that whenever a series of warm, rainless days, accompanied with drying winds, occurs in May or June, the vegetation of crops comes almost to a standstill. The development of young clover, for example, ceases wellnigh completely. But it is only after a long while that the clover begins to wilt, and at first the wilting is only visible in patches where the fields happen to be stony. But when wilting has once begun, only a few more days of hot, dry weather are needed in order to bring the entire field into this condition, and indeed to burn off and destroy the crop.

Once he took occasion of a sunny forenoon to collect and analyze some of the wilted clover plants at the first moment when wilting was shown by some patches of the plants. He found in the wilted leaves 71% water and 29% dry substance; in the stalks, 78.4% water and 21.6% dry substance; while in adjacent plants that had not yet wilted, he found in the leaves 82.5% water and 17.5% dry substance; in the stalks, 90% water and 10% dry substance.

Since the wilted plants contained nearly twice as much dry substance as the others, it appears that they must have lost almost half their water before their sufferings were manifested by the wilting; and the inference is, that long before the plants wilted they must have been living under abnormal conditions. In case it should have happened to rain freely the day before these plants were collected, no wilting would have been seen, although the crop had undoubtedly already, and for some time previously, been seriously crippled by the drought. In general, it may be said that the wilting of a crop affords no evidence whatsoever that the plants had previously been properly supplied with water. A discussion of the highly important question as to the amount of water needed by crops will be considered under the heads Barley and Oats.

Quantity of Rain that falls.

In New England very large quantities of water come to the land in the form of rain and snow. Inasmuch as one inch of rain delivers 4.673 gallons to the square yard, or 22,617 gallons (101 long tons by weight) to the acre,[1] a rainfall of 40 inches, or even of 20 or 30 inches per annum, must supply an enormous amount of water to every acre of land. The chief trouble is the unequal distribution of the rain-water. In many regions, the land is drowned and baked by turns.

Amount of Water used in Irrigating.

Practically, very large quantities of water are thrown upon grass-fields in countries where irrigation is habitually practised. In Italy, as Baird Smith concludes from the observations of several different engineers, an amount of water that would form a layer or stratum about four inches deep over the entire surface of the field, if it were possible so to spread it, may be regarded as sufficient to give a meadow a proper drenching. It is assumed in this case that about half the water will soak into the soil, while the other half flows off and is available for use upon lower-lying fields.

A familiar unit of measure for irrigation water is the rate of one cubic foot per second. The water is delivered through inlets of such height and breadth, and under such a head of pressure, that the number of cubic feet per second can readily be calculated by means of formulas which have been devised by the hydraulic engineers.

According to an experiment of De Regi, the continued discharge of 1 c. ft. of water per second is sufficient for the irrigation in 24 hours of 4 acres of mowing field. The total amount of water discharged will be 86,400 c. ft.; and as the area watered is 174,240 sq. ft., it appears that there is water enough to form a layer nearly 6 inches deep over the surface of the meadow. Twelve such waterings are given in the season, at intervals of a fortnight. The above estimate implies, however, that the whole of the water is absorbed by the soil, which is never the case in actual practice. Lombard engineers calculate that from ½ to ⅓ of the water applied is absorbed by the soil. Naturally enough, there is great diversity of opinion even in Italy with regard to the quantity of water that should be given to meadow land; and on some of the English water meadows quantities of water even larger than the foregoing are said to be expended.

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[1] To convert cubic inches into gallons, multiply by 40 and divide by 11.091, or multiply at once by 0.003607.

Modes of estimating the Water used in Irrigation.

There are three ways in which the total quantity of water employed is estimated: 1st, by the volume of water in continued discharge required to irrigate a given area of land; 2d, by the total depth of water spread over the soil, either at each watering, or during the whole season of irrigation; and 3d, by the total cubic contents of the mass of water employed. Smith says that the statistics of irrigation in India show that the continued discharge of one cubic foot of water per second is sufficient for the irrigation throughout the year of nearly 180 acres of land. Here the climate permits the use of the water the whole year through. In this estimate all kinds of cultivation are included, though it is well known that the consumption of water for different crops is extremely variable. Rice, sugar-cane, cotton, cereals, etc., each require their own special quantity of water.

On summing up the results of French and Italian experience, Buffon concluded that the irrigation of an acre of meadow requires under average circumstances the continued discharge of 18½ cubic inches of water, which gives an effective power per cubic foot per second of 93 acres. Smith believes this to be a very close approximation to the truth, and he gives the following summary in support of it:—

De Regi's estimate	96	acres per cubic foot per second.
Milanese “	78	“ “ “ “
Veronese and Mantuan estimate .	68	“ “ “ “
Tadini's estimate	96	“ “ “ “
Buffon's “	93	“ “ “ “

The reason why this estimate amounts to but little more than half the Indian, is that in Italy the water is seldom used during more than half the year. The great mass of the water consumed in Italy is used between the middle of March and the beginning of September.

Water Meadows.

It was customary at one time long ago in Europe to arrange farms in such wise that each farm was based upon the occasional irrigation of one portion of it; and many such farms are still maintained there upon the Continent. The idea was, that, by means of a just proportion of permanent grass-land kept constantly productive by irrigating it, so many cattle may be maintained that the rest of the farm can be manured with the dung of these cattle. Those parts of the farm which are not devoted to grass are thus made to produce crops of grain, or other merchantable products, at the expense of the watered meadow. This method of procedure is a very old one, and it was most commonly put in practice when the European countries were comparatively speaking new and poor, much as New England is now. Doubtless there are hundreds of farms in New England that could be kept up, somewhat in this way, at trifling cost, in places where the fields are now seen to be burnt to a crisp in the August droughts, and comparatively sterile throughout the year.

Almost everywhere in New England there are to be found light, leachy, hungry soils, based upon sand or gravel, which become dry at the surface in a few hours after rains, and dry up completely in times of drought, often to the depth of many feet. Such soils are so easily worked, and are ready for the plough so early in the season, that they attract many farmers, especially those who are weak as to teams and laborers; hence they are very often cultivated. One point to be made in favor of these drift-gravel loams is, that they have a wide range of workability, so to speak; that is to say, they may be ploughed and tilled at almost any time, excepting when they are soaking wet, or perhaps when they are baked dry. It is not so with clayey soils, which remain cloddy when ploughed dry, and work like putty when ploughed wet; and so, too, of some fine silts, or silt-like loams. Such soils as these last have to be ploughed when "just right," or a risk is run of injuring their tilth for years.

When well manured, the light New England loams just now spoken of give good crops in wet seasons, though in dry summers they often yield nothing or next to nothing. When left as pasture, the worthless oat-grass or "white-top" (Danthonia) tends to supplant all useful forage. But such lands, if irrigated, would every year yield good crops, and they could readily be kept up as permanent pastures.

It seems hardly consonant with the fitness of things, when half-starved cattle are seen searching a brown hillside, in times of drought, for some scanty blades of grass, when ample supplies of water are close at hand that might readily be applied to make the hillside fertile.

It is not alone ponds, and water-holes, and low-lying brooks, that are neglected among us; there are multitudes of active brooks in the hill country, the waters of which need only to be diverted, and regulated as to their rate of flow. It would be easy to form, in this way, fields which would produce a crop of hay in June, and afterwards furnish abundant pasturage throughout the summer.

In the long summers of Italy permanent irrigated meadows are mown thrice, and occasionally even four times, in the season, and they are subsequently pastured in the autumn. Baird Smith has calculated the annual production from an English acre of such meadow as follows:—

Hay from 1st cutting	2,730 lb.
Hay from 2d "	2,072 "
Hay from 3d "	1,557 "
Total hay per acre	6,359 "

I. e. rather more than three tons of hay, beside the pasturage, which is reckoned to be worth about $2 the acre.

Irrigation is widely practised.

As applied to mowing lands and pastures, irrigation is common in Germany, in Switzerland, and in the Tyrol, as well as in some parts of France and Spain, while in several provinces of Italy the practice is said to be wellnigh universal. In Italy, irrigation is applied to Indian corn also, and to rice of course, though rarely, it is said, to other kinds of grain. But in India, grain, sugar-cane, cotton, and a great variety of other crops, are habitually irrigated. As regards grain, in particular, much depends in any given locality upon the time of year when rains fall, and upon the amount of the rain.

In general, the practices of tropical countries, in many parts of which irrigation is an absolute necessity in order that plants may constantly be kept succulent enough to grow, must not be compared too closely with the requirements of temperate lands, although it is most conspicuously true that irrigation is at its best in hot climates. In the words of Townsend, writing of Spain, "It is astonishing to see, in a warm climate, the rapid growth of plants that are well supplied with water. The smallest cutting of a vine will in the space of 15 or 16 months cover the front of an extensive edifice, or form a spacious arbor from which the assembled family may gather in abundance the most luxurious grapes. In such a situation the seeds of limes, oranges, and lemons, will in 4 or 5 years produce a shady grove; and mulberry trees, when wholly stripped of their leaves for the nutriment of silkworms, will again in a few days be covered thick with foliage. Thus Adanson, in his account of Senegal, informs us that, when everything green has been devoured by locusts, not a vestige of their destructive progress can be discovered after the lapse of a few days."

The following example of an Italian rotation is given by Baird Smith: 1. Wheat, to be reaped in July, grass-seed being sown with the wheat. 2, 3, and 4. Meadow under irrigation and abundantly manured. 5. Indian corn, or flax. After the flax is cut, at the end of June, millet is sown, which comes to maturity in October. Sometimes another crop of maize is taken in the sixth year, before returning to wheat.

Ruin caused by the Destruction of Irrigation Works.

With regard to other countries, the underground canals in Persia, and the cisterns, water-tanks, and irrigation ditches in India, are prominent features everywhere, to judge from the constant mention of them by travellers, and so it was formerly in Palestine and Syria. According to Mr. Marsh, it is to the destruction of the ancient reservoirs that the diminished fertility of these countries must be attributed. The surface of Palestine, he says, is composed in great measure of rounded limestone hills, near the tops of which reservoirs were hewn in the rock to retain the winter's rains, while the declivities were terraced. So long as these cisterns were in good order, and the terraces kept up, the fertility of Palestine was unsurpassed; but when misgovernment and wars occasioned the neglect or destruction of these works, traces of which still meet the traveller's eye at every step, when the reservoirs were broken, and the terrace walls had fallen down, there was no longer water for irrigation in summer, the rains of winter soon washed away most of the thin layer of earth upon the rocks, and Palestine was reduced almost to the condition of a desert. So, too, in the neighboring countries. In Egypt, as Mr. Marsh explains, evaporation and absorption by the earth are so rapid, that all annual crops require irrigation during the whole period of their growth. As fast as the water of the river retires by the subsidence of the annual inundation, the seed is sown upon the still moist uncovered soil, and irrigation begins at once. Upon the Nile the creaking of the water-wheels, and sometimes the movements of steam pumps, are heard through the whole night, while the poorer inhabitants unceasingly ply the simple bucket and sweep, laboriously raising the water from trough to trough by as many as six or seven stages when the river is low. The quantity of water thus drawn from the Nile is enormous.

The conditions, as regards soil and climate at least, under which irrigation is practised in Italy, would seem to be nearly akin to those which obtain in New England. According to Mr. Marsh, the summers in Northern Italy, though longer, are very often not warmer than in New England; and in ordinary years the summer rains are as frequent and as abundant in the former country as in the latter. Yet in Piedmont and Lombardy irrigation is generally practised. In the great alluvial plain of Northern Italy, where irrigation is so common, the soil is very extensively underlaid by beds of pebbles and gravel brought down by mountain torrents at a remote epoch, just as multitudes of loamy fields in New England are underlaid by the gravelly glacial "drift." In the year 1856 about four thirteenths of the old kingdom of Sardinia were irrigated, — some 600,000 acres namely. In Lombardy there were 1,100,000 acres, and in France about 300,000 acres. Mr. Marsh held that there was every reason to believe that the practice of irrigation will greatly increase in the South of Europe. He estimated some years since that the artificially watered soil of Italy would be doubled, and that of France quadrupled, before the end of this century. He tells us that two of the canals in Lombardy, by which some 250,000 acres of land are irrigated, were dug in the twelfth century.

Antiquity of Irrigation.

Indeed, it is a very curious fact in the history of irrigation, that the art attained a high degree of excellence at a very early period, and afterwards suffered a great decline, when the countries that practised it were conquered and overrun by nations ignorant of the art. Not only did this happen in Palestine, and in Persia and the adjacent countries, but the same result came to pass in Spain, and in Mexico and Peru when the Spaniards overrun these countries; and so it was, too, in India, when the English first took possession of the land. The only difference was, that in some of these cases, as in Palestine, the irrigation works were completely destroyed, while in others they were merely neglected or curtailed, so that the development of the art was checked. The Moors who took possession of Spain in the sixth century were skilful irrigators, and they constructed great works to this end all over the country, and in the southern part of France. But when the Spaniards expelled the Moors, the greater part of the irrigation works went to ruin. Just so it was in Peru and in Mexico, the invaders being less civilized than the invaded in this particular respect. But in spite of their ignorance, the Spaniards did, nevertheless, learn enough about irrigation to keep the art alive, after a fashion. Indeed, in some parts of Mexico they constructed extensive works, and it is from contact with the Spaniards in California that Americans have begun to learn something about the subject.

There is every reason to believe that the art will henceforth prosper in this country, now that people are really interested in it. Not that it is probable that the Americans will speedily attain to the same kind of perfection which was reached by the Spanish Moors. It is not at all likely that our people will try to carry out the details so nicely, so methodically, and so systematically as the Moors did. But it is to be expected that they will adapt the art very completely to the requirements of the present day, and obtain highly profitable results by means of it. At any moment now, it may become fashionable in many parts of this country to establish irrigation works, and for practical men to insist upon the merit of the art as if it were a new discovery.

In India, the English, after many years of comparative neglect, took up the matter zealously, and they have done much to extend and improve the methods of irrigation which are practised in that country.

The following citation from Birkbeck relates to the Moorish system. In describing the southeasternmost corner of France, where it touches the Spanish border, he says: "How this country was originally laid out so judiciously, with channels of irrigation systematically arranged for the benefit of the whole, is a mystery I have not heard explained. A master's hand seems to have planned and executed all, before the appropriation of the soil; otherwise, private interest would have interfered and marred the design. Every man now finds a canal for bringing on water passing above his field, and a canal for drawing off water at the bottom, the latter serving in its turn to let on water for the land below."

"The manner of applying the water is extremely simple. A dam is made across the upper channel, from which the water flows gently into a furrow made by the plough along the higher side of the field, and in a few hours soaks through the whole soil, until it reaches the lower side, which completes the operation. The following course of crops, which is one of the usual practices of the district, may show what this amphibious husbandry can effect. In August they scratch the wheat stubbles with their little Roman plough, which does not turn a furrow, nor move a fourth of the surface; they then sow annual clover [crimson clover, T. incarnatum], and plank it in by dragging over the land a plank, on which a boy rides, thus breaking the clods and smoothing the surface. The weeds and stubble are but little affected by these substitutes for ploughing and rolling. But this is no matter, for, the water being now introduced, the clover starts instantaneously as it were, and is knee-deep by October or November, when it is fed off by sheep. Water is applied from time to time, and in January or February the clover is fed again. Finally, it is mown for hay in May, yielding a heavy crop. As soon as the hay is off the land, another scratch is given, millet or beans are sown, irrigation goes on, the crop is reaped, and the ground receives four ploughings as a preparation for wheat, which is sown in October or November. . . . . This is the history of one year; and is a familiar and constant practice in this region."

Some Evils of Irrigation.

It is but fair to say, that the practice of irrigation is attended with certain drawbacks, excepting in broken and hilly countries, like some parts of New England, where springs and rivulets are numerous. According to Mr. Marsh, any large-way system of irrigation necessarily brings in its train very serious evils, both economical, social, political, and, as he might have added, malarial. The construction of canals and their immensely ramified branches, and the grading and scarping of the ground to be watered, are always expensive operations, and they often require an amount of capital which can be commanded only by the state, by moneyed corporations, or by very wealthy proprietors.

The capacity of the canals must be calculated with reference to the area intended to be irrigated; and when they and their branches are once constructed, it is very difficult to extend them, or to accommodate any of their original arrangements to changes in the condition of the soil, or in the modes or objects of cultivation. The flow of the water being limited by the abundance of the source, or the capacity of the canals, the individual proprietor cannot be allowed to withdraw water at will, according to his own private interest or convenience, but both the time and the quantity of supply must be regulated by a general system, applicable, as far as may be, to the whole area irrigated by the same canal; and every cultivator must conform his industry to a plan which may be entirely at variance with his special objects, or with his views of good husbandry.

The clashing interests and the jealousies of proprietors depending on the same means of supply are a source of incessant contention and litigation, and the caprices or partialities of the officers who control or of the contractors who farm the canals, lead not infrequently to ruinous injustice towards individual landholders. In Europe, these circumstances have discouraged the division of the soil into small properties, and there is a constant tendency to the accumulation of large estates of irrigated land in the hands of great capitalists, and consequently to the dispossession of the small cultivators, who pass from the condition of owners of the land to that of hireling tillers. The farmers are no longer yeomen, but peasants.

Manifestly, however, these evils, as set forth by Mr. Marsh, are of the same general character as those which accompany all corporate action, and all kinds of corporate enterprises. They are cited here, because they enforce the lesson, that, if nations so much less favorably situated than the New Englanders are can afford to submit to the inconveniences enumerated for the sake of the benefits which irrigation offers, there must be all the more reason to condemn the inertness of those American farmers who, by utilizing the waters of their own brooks, might gain all the advantages that are to be had from irrigation without encountering any conflicting interests, or opposition, or annoyance of any kind.

Ways of obtaining Water.

Naturally, the simplest and easiest method of obtaining water is to direct the flow of some brook or spring lying at a higher level than the field to be irrigated. But there are many ways of lifting water at small expense, which might frequently be employed with advantage in agriculture and horticulture. The hydraulic ram is an efficient and an inexpensive instrument, which can do a great deal of work without need of much supervision. It might be used for purposes of irrigation in many situations. It is surprising that an instrument in such common use in this country for pumping water into houses and stables should be so seldom employed for watering fields. There are aspirating siphons, and water-lifters, actuated either by a head of water or by steam, which are extremely simple both as to their construction and their manner of working, since the motor acts directly without the intervention of any complicated machinery.

Windmills also, such as were formerly abundant on the sea-coast of Massachusetts in the days when salt-works were necessary or profitable in this region, might sometimes be used to lift water for irrigating, though their action is necessarily intermittent, and there must be reservoirs connected with them to be filled when the wind permits.

Many varieties of steam pumps can be run at small cost, some of them with entire safety also. So, too, there are cheap engines, actuated by hot air obtained from an ordinary stove. These engines need but little attention, and are no more dangerous than a cooking-stove. Even where an engine is required, it is an easy matter to lift water to a moderate height at small cost. A slow-moving, great wheel-pump will scoop up water very cheaply to the height of a few feet, if only time enough be allowed for it to work; and such a pump may be driven either by steam or by water power if it be at hand. But for the undue cost, the wheel might be driven indeed, if need were, by horse power, or by means of cattle, or even by manual labor, as at the East.

At some future time, doubtless, pumping engines will be driven directly by the heat of the sun, for there is everywhere an enormous amount of force to be had for the taking from hot sunshine. Several engines for utilizing the sun's heat as a motive force have already been devised. Mr. Ericsson, among other inventors, claims to have made efficient engines of this kind. There is indeed every reason to believe that the ordinary methods of agriculture will eventually be entirely changed in many countries — perhaps in most countries — by the adoption of methods of irrigation founded upon pumping water by means of engines driven by the sun's heat.

Reservoirs for Irrigation Water.

As for the reservoirs into which the water is pumped, or in which water from any source is stored, there is usually no need that they should be of expensive construction, though it will be well to have them tolerably large. In general, it may be said that a layer of puddled clay will hold water, and that a methodized mud-puddle might, in many instances, serve an excellent purpose. Explicit directions for the making of cheap pools and ponds are given by the early English writers, and a good deal of attention has been given to the subject in Europe, as bearing upon the making of fish-ponds, ornamental waters, and field reservoirs for cattle. In some tolerably firm soils, a mere coating of cement applied directly to the soil is said to be sufficient to make a water-tight hole; but it would have to be carefully shielded from frost. And here, in fact, is the weakest side of irrigation, in regions where the winters are cold. In such countries the risk of damage from frost must always be a great hindrance to the establishment of dams, cisterns, reservoirs, terraces, or constructions of any kind.

Modes of applying Water.

It would be quite beyond the scope of this work to attempt to describe in detail the mechanical devices by means of which water is applied to the land in systems of irrigation. Many special treatises upon the subject have been published, and may be obtained through any bookseller. It is to be remembered, however, that many of the complex and elaborate arrangements of ditches described by the older authors were devised at a time when grass was mown wholly by hand, i. e. with scythes, before mowing-machines had come into use. To meet the requirements of these machines, narrow open ditches, with steep sides, had better be dispensed with in so far as may be possible.

One simple way of irrigating where the land is somewhat sloping, and in grass, is to bring the water into a long ditch at the head of the slope, and to lead it thence into smaller ditches, from the sides and ends of which project still smaller cuts. By means of gates and check-boards of the simplest conceivable construction, the flow of water into the several ditches is regulated both as to its quantity and its direction. At the heads of the smaller ditches a mere sod is often used as the gate. By treading the sod down firmly in the mouth of the ditch, the flow of water is checked, and by taking up the sod the ditch is opened.

The entire system of ditches is so arranged that a thin but regular sheet of water may be made to flow at will over any and every part of the field. Whatever water does not sink into the soil is collected in another main ditch at the foot of the slope, and so carried off; or, where the slope is long, the surplus water may go to feed a second complex of ditches similar to the first. After the flow of water has been kept up for two or three days, the supply is shut off, and the field allowed to dry.

In Italy the surplus or drainage water which collects at the bottom of the slope is highly esteemed, since in that country it has almost always passed over richly manured land, and has thus become more highly charged with fertilizing matters than it was originally. The Italians attach considerable importance also to the fact that the temperature of the water becomes higher as it flows over the land, and is in so far better fitted to promote nitrification and to force the young grass.

The operation of flowing is repeated as often as the weather may dictate throughout the season. The idea is, that a thorough soaking should be given to the land at proper intervals, but that the water should never be left on long enough to exclude air from the pores of the soil for more than a comparatively brief space. If air were thus excluded, there would be a risk of exciting reducing actions which would make the land cold and sour, so that useful grasses would be killed, and the growth of rushes, sedges, and other swamp plants be encouraged. In irrigating meadows, it is held to be essential to have ready means of drainage in order to prevent any stagnation of water on the land. As Townsend insisted, long ago, "Stagnant water is at all times unfriendly to meadows. Such water may remain upon the surface of the soil for weeks or months, subject to decomposition, but instead of being in this state beneficial, it is injurious to crops. In water meadows, we uniformly observe that it is not humidity which does good, but a thick sheet of water flowing incessantly night and day for a certain period over the surface."

Irrigation keeps Land "sweet."

On the other hand, it is noteworthy that one prime merit in irrigation, where good water is properly applied, consists in its killing out mosses, sedges, and the like, from low-lying meadows. The inference is, that this result is accomplished by the water's washing out from the soil soluble humic acids, sulphides, ferrous sulphate (?), and other products of processes of chemical reduction; — products, that is to say, which are prejudicial to the growth of good grasses, but which can be supported by the inferior plants just mentioned.

By thus killing off the bad plants, and encouraging the growth of better grasses, irrigation may not only increase the yield of hay upon a meadow, but improve the quality of the hay. In a similar sense it is to be remarked that brook-water which is actually moving (living water, as the term is) is far less destructive to some really worthy grasses than cold or stagnant water.

Ribbon-grass, for example, will grow freely even in situations where a thin layer of brook-water flows over the land wellnigh continually. Such water probably contains a good deal of air in solution, for one thing; and for another, it must dilute and wash away any soluble hurtful products which may form in the wet soil. But if the water were left for so long a time simply to stand upon the land, or to soak into it, and were not continually in motion, the grass would be liable to perish.

It often happens that upon a hillside a single ditch drawn across the head of the slope will be sufficient to spread the water tolerably equably over an entire field. Between the system depending thus upon a single ditch, and the more elaborate system just now alluded to, there may be devised an almost infinite variety of arrangements. Practically, the farmer will make his complex of ditches more or less methodical according to the lay of the land and the character of the inequalities upon its surface. But the irrigation, considered as a method of manuring poor land, will manifestly be the more complete in proportion as the number of the distributing ditches is greater, because of the fixation of fertilizing matters by the soil where the water first comes in contact with it. In case there is but a single ditch at the top of a slope, the dissemination of the fertilizing matters will be more or less restricted, and it has on this account sometimes been found well to change the position of the ditches occasionally when this could be done without much trouble.

The following analyses by Mayer exhibit some of the differences in the composition of incoming and outgoing water, as actually taken from an irrigated field. A litre (1,000 grams) of water contained the following amounts of dissolved matters, in milligrams.

	Live Water, i. e. incoming.	Drain Water, i. e. outgoing.
Lime	23.1	12.4
Alumina and oxide of iron	2.4	3.5
Phosphoric acid	trace	trace
Potash	4.2	2.9
Matter insoluble in muriatic acid, after evaporation and ignition (silica?)	11.1	13.3
Organic matter, etc.	7.1	10.2
Residue left on evaporation, i. e. sum of the dissolved matters	81.8	61.6

One system of irrigation consists in throwing up the land upon the banks of a brook into rounded beds provided with a shallow ditch at the crown or summit, and deeper ditches at the base of the bed, upon either side of it. The water of irrigation is lifted from the brook into the upper ditch, and made to flow down the slopes, upon both sides of the bed.

It is noteworthy that practical men in France direct that, in irrigating mowing lands, the water should be let on by night, and shut off during the day; and that no water should be applied for a week before the grass is mown. So too, after the hay harvest, and after time has been allowed for the cut stalks to become dry, the water is let on by night only, and is shut off by day. The practice is clearly philosophical from the chemical point of view; food is provided for the grass by night, and the light and heat of the day are permitted to act without hindrance upon the growing crop.

Whenever it is proposed to irrigate grass-land, care must be taken that the grasses grown there are of kinds fit to be irrigated. Unless this point is attended to, it might happen that no advantage whatsoever would be gained by bringing water upon a dry field.

One important consideration must not be lost sight of, and that is the power which irrigation gives the farmer to regulate the temperature of a field. In case there is danger of frost, for example, either in spring or in autumn, it will merely be necessary to flood the field through the night in order to protect the grass from harm. In the excessive heats of summer, also, the coolness resulting from the evaporation of the water from the moistened soil keeps down the temperature of the plant to a healthy limit.

Sewage Irrigation.

In the neighborhood of cities and large towns it has occasionally been found practicable to irrigate land with water from the sewers, and since the sewage is more highly charged than ordinary water with fertilizing matters, excellent results have occasionally been obtained in this way. The irrigated fields outside of Milan and Edinburgh have long been famous, and of late years portions of the sewage of London, and Paris, and Berlin, and several other cities, have been applied in a similar way.

I have myself examined the grass-land outside of Edinburgh, which is irrigated by the sewage of that city, and I can testify that the published accounts of its wonderful fertility are in no sense exaggerated. The vigorous and rapid growth of the grass, and the number of crops obtained in the course of a year, as well as the size of these crops, are simply marvellous. The meadows in question begin in a narrow valley close to the city, and extend at intervals a distance of several miles down to the sea. There is a narrow, deep, open brook, which is manifestly natural, flowing through the middle of this valley, and carrying the sewage of a part of the town, Although the covered sewers of the Edinburgh streets, bearing much filth from cesspools and water-closets, flow into this brook, I could not perceive that any unusual odor was given off by the water, except on very careful inspection. A stranger knowing nothing of the matter would notice only that the water of the brook is unusually dark and muddy. This freedom from odor is doubtless due to the circumstances that the brook falls away from the city rather rapidly, and that a great deal of ground-water from the higher parts of the city is constantly flowing into the brook together with the sewage. The coolness of the ground-water and the rapid fall tend to prevent the sewage from putrefying, and the access of ground-water dilutes it to a state of comparative sweetness. The rain-water from the streets of the city also flows through the sewers into the brook, and it was easy to see, from the pieces of drift stuff hanging from bushes and the edge of the bank, that the brook is often swollen to an extent very much greater than at the time of my visit. Hence it is scoured periodically.

Thanks to the very considerable difference in level between the city and the meadows, the falling brook is made to work hydraulic rams at several points, so that as much of the sewage as may be desired can be pumped up to the highest edge of the meadows. There it is received in a long, and comparatively speaking deep ditch, running parallel with the brook. From the top of this ditch, at distances of two or three feet from one another, small rills run off at right angles to the direction of the ditch, in such manner that the sewage water can flow all over the slope between the upper ditch and the brook in the middle of the valley.

The grass, which comes to be of a rather coarse, but in no sense "sour" quality, is cut five, or even six times a year, to be used as green fodder; it is not made into hay. There is a constant succession of cuttings from early spring to late autumn, and after each cutting the plot is irrigated once. The luxuriance of the grass is most remarkable, and so is the freedom of the place from smells. I went across and around these meadows in all directions one warm day in the middle of September, and was quite unable to discover any offensive odor, either at the points where the rams were working, or where there are some rapids in the brook, or at the upper ditches, or at certain settling pools or ponds which occur at intervals in the course of the brook, and which have been made for the purpose of catching the mud which the brook brings down. At the feeding ditches scarcely any odor could be detected, although some of them were half filled with mud and filth in process of drying. At the rams there was a certain unpleasant smell, but it was very slight and altogether local. My companions, who were old citizens of the town, insisted that, even during the hottest days of summer, no appreciable odor can be detected on these meadows, so perfectly do the earth and the growing grass absorb and consume the putrescible matters of the sewage. When the water is shut off from the upper or feeding ditch, and the ditch becomes dry, a certain quantity of mud is scraped out from it, which is sold to market gardeners to be used as manure. In the same way, the mud from the settling pools is scraped out and sold.

It is said that, previous to the irrigation of this tract, it was a worthless, neglected sandy waste. $2.50 the acre would then have been a high rental for land that is now let at the rate of $150. The original sand was dug out to be used in the city, and in its place rubbish of all sorts from the city was laid down; it being a comparatively easy matter to grade the surface of the rubbish so as to fit it for receiving the water evenly.

At Edinburgh the sewage is applied only to grass, though the deposit from the pools is used as a manure for all sorts of vegetables. The fact that this irrigation is so successful in the moist climate of Scotland goes to enforce the argument that irrigation must be looked upon as a chemical process. It will be noted also, that the rubbish subsoil affords an open porous land, much as if it were filled with tile drains.

In 1877 there were 400 acres of these "forced meadows" near Edinburgh, and they are said to increase gradually. The Craigentinny meadows, just now mentioned, were about 200 acres in extent, and they had then been irrigated for 30 years and more. They were laid down at first to Italian ray-grass and a mixture of other grass seeds, but these artificial grasses disappeared long ago, couch-grass and various natural grasses having taken their place. The grass is sold green to cow-keepers, and yields from $80 to $150 per acre. One year the price reached $220 per acre. They get five cuts between the 1st of April and the end of October. This farm of 200 acres turns in to its owner every year from $15,000 to $20,000, at the least calculation, and his running expenses consist in the wages of two men who keep the ditches in order. The sewage he gets free. The yield of grass is estimated at from 50 to 70 tons per acre.

The total produce of the sewage irrigation at Edinburgh amounts to at least $30,000 per annum, taking one year with another. The grass goes to some 2,000 cows, and the milkmen all acknowledge that they cannot get any milk-producing food to compare with it for the same amount of money, notwithstanding the seemingly high price that is paid for the grass per acre. Of course the dung from these cows goes to fertilize other farm land.

The only question is, whether there may not remain adhering to grass which has thus been bathed with sewage some germs of typhoid, cholera, or other vile diseases, which are propagated in human excrements. In view of what is now known of the modes of transmission of such diseases, it is difficult to look with entire complacency upon the act of feeding cows with grass thus liable to contamination, or of throwing about such grass in stables where milk is exposed to the air during the operations of milking, straining, and canning. It must be admitted, however, that this objection is purely hypothetical. Practically, milk and beef from cows fed upon sewaged grass seem to be perfectly healthful foods, and so do vegetables that have been grown on sewage farms.

There are few great cities in the world, however, beside Edinburgh and Milan, where arrangements such as those just described are possible. Any land so near a growing city as these meadows are to Edinburgh is far too valuable for buildings, for agriculture to hope to lay any claim upon it. But, as has recently been done at London, Paris, Dantzic, Berlin, and several smaller cities, it is possible to pump the sewage into reservoirs, and then carry it through aqueducts for as many miles as may be necessary for the sake of fertilizing some barren waste. In such cases the only question to be asked, from the agricultural point of view, is whether the waste land could not be reclaimed more cheaply; whether, in fact, the money spent in erecting and maintaining the pumps, aqueducts, reservoirs, and works of irrigation might not be used to better agricultural advantage in importing guano or fossil phosphates, in composting peat, or bringing potash from the Stassfurt mine, or even in irrigating the land with mere water from some adjacent brook.

Generally speaking, the cost of carrying sewage to the farm land simply for the sake of the fertilizing materials contained in it would be far too large to admit of any such project being seriously thought of. It is only where waste land is readily accessible, and so situated that the sewage can flow to it by mere force of gravitation, that this liquid can be economically employed as a manure. Usually the conditions in the vicinity of cities are such that a long and costly system of pipes would have to be carried over hill and dale for the conveyance of the sewage, and the liquid would have to be lifted by means of steam pumps in order that it should flow through the pipes. But the cost of any such constructions as these could not fail to be larger than the agricultural value of the sewage, and no farmer or combination of farmers could possibly afford to pay for them. Hence it follows, that, whenever city sewage is to be conveyed to farm land, the necessary apparatus will have to be built and maintained by the city, solely for the sake of getting rid of the filth.

It was thought at one time that sewage thus carried out from a city might be sold to the farmers, or even given to them gratis, in case they were indisposed to pay for it. But this scheme has been found to be impracticable.

There can be no question that sewage, even the weakest, would be a valuable manure if the farmer could find it at the edge of his field, brought there at little or no expense to himself, as is the case at Edinburgh, and if the privilege were allowed him of using the material at any moment, and in such quantities as he might choose, or of not using any at all if he thought best. Unfortunately, such freedom of action as this would be quite incompatible with that constant and complete purification of the sewage which is the one particular point the city has to care for. Consequently, in most instances where sewage irrigation is practised, the cities have had to buy and lay out tracts of land for themselves, and to farm them also, at high cost.

Possibly a time may come, under some forms of government, when it would be economically practicable for a city to divide the irrigated tract into a number of small farms, and to lease these farms to the highest bidders, subject, of course, to stringent rules and regulations as to the manner of using the sewage. In this way the farmers would get the sewage for just what they could afford to pay for it; that is to say, the final result would come to this, after the value of the farms had been indicated by the experience of a term of years. The notion that sewage might be carried in pipes through considerable districts and sold to the farmers there resident is now regarded as chimerical, because of the absolute necessity of having a constant, definite, and certain outgo for the liquid. Nothing in the least degree uncertain or precarious can be permitted in this regard.

The experience of several European cities teaches that, though specially well adapted for manuring grass, sewage serves excellently well for most roots, and for vegetables also, care being taken, of course, not to let any of it come in contact with their leaves. Grass does better than any other crop, since it continues to grow through so large a portion of the year, and Italian ray-grass has approved itself to be supremely excellent. Good crops of it can still be raised on land which receives an enormous quantity of sewage. This grass admits of being irrigated almost constantly for some time, whenever it becomes necessary to do so in order to dispose of the sewage.

On the English sewage farms land beds underlaid with tile drains are provided, and the soil of these beds is soaked with the sewage more or less frequently and thoroughly. According to one account, the soil on which ray-grass is growing is soaked, for a few hours, two or three times, at intervals of a fortnight after the grass has been cut, the sewage being applied at the rate of 400 or 500 tons to the acre, which is equivalent to a layer of water about 4 or 5 inches thick. When the field is again mown, it yields some 10 to 16 tons of grass to the acre. In the course of the year, from 4,000 to 6,000 tons of the liquid are applied to each acre of land; 5,000 tons has been commended as a good annual application.

In the experiments of Lawes and Way, taking the average of three years, 3,000 tons of sewage to the acre gave 22¼ tons of grass per annum, 6,000 tons gave 30¼ tons of grass, and 9,000 tons of the sewage gave 32½ tons of grass, while a contiguous field not sewaged gave 9¼ tons of grass to the acre. In terms of hay, these crops were 5, 5¾, 6½, and 3 tons respectively.

At Croydon, in England, eight cuttings of ray-grass are taken, the first in January, and the last in December. Here the grass is irrigated from 24 to 48 hours each week. Vegetables, however, are irrigated not oftener than once a fortnight, and, if the season is wet, the watering is repeated only at intervals of 4 or 6 weeks. Excepting ray-grass, they would be glad not to irrigate any crop within a week of the time of harvest. In Wales, where the summer is shorter, the first crop of ray-grass is mown in April, and the last in November, four cuttings being obtained in all.

At Milan, in Italy, sewage irrigation and ordinary irrigation are said to overlap one another. Half the land in the neighborhood of that city is kept continually in grass. Thanks to the mild climate and to the warmth of the sewage, which, as it flows from a city, is always at a temperature above the freezing point of water, grass can be started very early in the spring by judicious flooding, and be kept growing until late in the autumn. Practically, at Milan they obtain a cutting of grass about a foot high on the 1st of February, and as many as nine cuttings in the course of a year. A thorough system of overflow exists for a radius of about ten miles southward and eastward of Milan. One noteworthy point in respect to Italian irrigation is, that the farms are to-day extremely fertile. Exhaustion of the land is not thought of, though the art of irrigation has been in use there ever since it was brought from the East by the Crusaders. As has been said, the fields are continually manured with the dung of animals that have been fed with the grass, the use of sewage being altogether exceptional in Italy.

Irrigation is peculiarly applicable to grass-land, because the sod tends to prevent the soil either from gullying or from being puddled and encrusted by the action of water. Pasture-land may be flowed freely, even when its surface is very steep and very irregular, as is seen in Switzerland; but in order that other crops may be irrigated, upon hillsides at least, it is often necessary to build terraces, so that the soil may be supported and the water distributed. The expense of these constructions is so great, that they are resorted to only in hot climates, where irrigation is an absolute necessity, and where there are no frosts of winter to destroy the embankments.

Subterranean Irrigation.

As regards crops other than grass, there is the trouble that, when water is repeatedly put upon ploughed land, it tends to float up and puddle the finer particles of earth, which subsequently, on drying, often make the surface soil so hard and stiff that the growth of the crop is hindered; even the soaking in of new supplies of water may be greatly delayed. It was probably, in part at least, for the sake of lessening this difficulty, that trials were made in Germany some years ago, on a tolerably large scale, of several subterranean systems of irrigation. The fundamental idea in each case was to carry the irrigating water about beneath the surface of the ground in tile drains. This method is said to have been found useful on soils of fair consistency, though not to be commended for porous soils, such as coarse gravels. One of its merits is, that much less water is needed than is usually expended in processes of irrigation. One observer has stated, that not a twentieth part of the water used in the old system is required for the successful working of the underground plan.

It would seem at first sight that the expense of laying the tubes in this system must be so great that it could hardly be expected ever to come into general use, excepting, perhaps, as a sanitary device for disposing of sewage. But it has been claimed, nevertheless, that meadows can actually, in some instances, be laid out more cheaply in this way than by the old plan of scarping, since the water can now be fitted to the land, instead of fitting the land to the water as before. Land thus underlaid with tiles can never become springy or stagnant, because it is drained by the tiles. The land may either be charged with water, or water may be discharged from it, at will; and all kinds of crops can be grown upon the land, as well as grass, either in alternation with grass, or to the entire exclusion of grass.

This underground irrigation is extremely interesting from the scientific point of view, since the conditions which obtain in a field thus irrigated beneath the surface must be somewhat similar to those which exist naturally in fields where the ground-water stands at the best level for the growth of plants. Indeed, it is to be regarded as one great advantage of the tubes, that they act as drains in the spring to keep the land free from any excess of water, and as conduits in summer to fill up the store of ground-water whenever the land has become somewhat dry. The surface of the land is left smooth withal, and unencumbered with ditches, so that it can be mown or cultivated and that cattle can run upon it.

Another merit of the system is, that far less water is evaporated from the surface of the ground than must necessarily occur in ordinary irrigation. All the heat that would be expended in evaporating the water is of course left for warming the soil.

Doubtless a good deal of useful knowledge as regards the best methods of dealing with ground-water could be arrived at by experimenting with this system of subterranean irrigation, and carefully studying its efficiency under varying circumstances.

As regards the avoidance of puddling by the action of the irrigation water, that could perhaps be done as cheaply by appropriate systems of mulching, as by means of the underground tubes. Wherever possible, it would seem to be best thoroughly to drain the land by means of tiles, and then to irrigate it either upon the surface, according to the usual method, or according to the newer plan. By operating in this way, the bad effects of "over irrigation," which are encountered sometimes in hot countries, might be avoided, at least in part.

Over Irrigation.

A soil from which no water ever drains away, and from which water is continually evaporated, must sooner or later suffer from over irrigation, for the conditions supposed are similar to those which produce the saline and alkaline deserts and desert patches of Utah, California, and Central Asia, where brooks have for ages run into the valleys and plains there to dry up. Waters that are slightly alkaline to begin with, though excellent for irrigation proper, would probably do more harm in such cases than ordinary water, since, according to Hilgard, the presence of as much as a quarter of one per cent of soluble alkalies in a soil is injurious. During the wet season, indeed, little harm may be done by the alkaline matters; but they accumulate at the surface when the rains have ceased, corrode the root-crowns of plants, and stunt or finally kill them. If there is more than a quarter of a per cent of the alkali in a soil, seeds are killed by it during germination.

Decrease of Irrigation in Central Europe.

The point has been made, that irrigation was formerly more frequent in Central Europe than it is now. One of the chief difficulties of the earlier farmers, in regions of light gravelly soils, was to procure enough fodder to keep their cattle through the winter. Before the introduction of clover and of turnips in England, and the practice of sowing English grasses, natural meadows were indispensable; and to increase the crop of hay upon them, they were watered in the spring, in case the season was dry, and in the summer also, after the first mowing. But when regular upland hay-fields and clover-fields were established, the need of water-meadows was less keenly felt, and many of them were abandoned. One reason for the change was, doubtless, that the hay from watered meadows is less highly esteemed than that from upland hay-fields. It sells for less money in open market, just as the hay from reclaimed bog-meadows does to-day. But this objection is really one of no great importance, since it has been learned that a very small addition of oil-cake, of gluten-meal, of bran or malt-sprouts, or perhaps even of corn-meal, will make the hay from watered meadows as good as that from uplands. There is another reason also for giving up water-meadows as a country becomes populous, and as its agriculture improves, in that much low-lying good land is needed for growing roots and vegetables, i. e. crops which are more remunerative than grass.

Warping.

There is a method of fertilizing land, known in England as warping, which differs from simple irrigation in that, instead of the matters dissolved by the water, a great quantity of mud is deposited upon the land. This method is applicable only in special localities, as upon the banks of the river Humber, where the land is low, and where the tide rises and falls sufficiently to admit of the establishment of embankments, and of gates and sluices, by means of which the muddy water may be brought upon the fields at high tide, and let out again when the tide is low.

When a field is thus flooded, the water is left at rest upon it until the solid matter which the water held in suspension has been deposited. Where warping is practised in the low-lying lands of Lincolnshire and Yorkshire, it often happens that a layer of mud as much as one tenth of an inch in thickness is left from a single flowage. By repeating the flowings often enough, it is easy to obtain a layer of excellent soil several inches, or even several feet thick. In some of the English localities, there is no difficulty in covering the warped ground with a foot of sediment in a single season. Usually, the land is covered from one to three feet thick with the warp deposit in one, two, or two and a half years. Generally, one such treatment is found to be sufficient; but sometimes the spongy moor subsides so much under the weight of the solid matter thus laid upon it, that it needs to be warped anew after a few years.

In one sense, the process of warping may be regarded as a mere exaggeration of what is sometimes seen in nature. Thus, the overflow of the river Nile is an instance of warping upon a stupendous scale, only that the Nile flows the land upon its banks but once in the year, while in the artificial system the flowage may be repeated with every tide until finished.

In England, warping is so much esteemed that the muddy water has in some instances been conveyed through channels to a distance of several miles before it is permitted to flow over the surface of the land. The process is said to be most beneficial on sandy and peaty soils. By means of it, large tracts of worthless land have been brought under profitable cultivation.

The completeness with which the suspended matter is sometimes deposited from the muddy water, when once it has come to rest, is remarkable. The fact depends, doubtless, on the presence of some sea-water in the muddy liquor, whereby the suspended particles are flocculated. The English chemist Herapath observed, in one instance, that a water which contained 233 grains of suspended matter to the gallon deposited 210 grains during the process of warping. The deposited matter is of course extremely fine, and well fitted for the support of plants after it has become mixed with the coarser sand or peat of the land upon which it is deposited.

Between this system of warping, taken in the extreme English sense, where the water acts merely as a vehicle for bringing in and distributing a great quantity of solid matter, and that variety of irrigation which consists in flowing a grass-field, or a cranberry meadow, or a rice-field, with water, considered merely as water, there is of course every conceivable degree of variation as regards the clearness of the water.

Flooding of Meadows.

The occasional flowing of grass-land by backing up water upon it is a common method of irrigation in Germany, especially in situations where the water supply is precarious or inconstant. In this system the water is left to stand at rest on the grass-land for a longer or shorter interval, and then drawn off completely. The fertilizing effects of the water may depend mainly, if not entirely, in this case, upon the matters dissolved in it which are retained by the soil.

This method of flowing or inundating is held in far less esteem, however, than that in which living water is made to trickle over the land. It is worth noting, nevertheless, that, in flooding a meadow, all the moles and mice and worms and insects which happen to be there will be destroyed and put out of the way of doing harm. Some kinds of useful plants will be killed also, but so will many kinds of weeds. It is easy to introduce good grasses, however, on flowed land, if only time enough be allowed, especially if pains are taken to encourage the desired kinds. It is to be observed, also, that one year's irrigation of a natural field may amount to nothing, because the grasses upon it may not be of kinds that profit by the wetting. In the practice of irrigation, botanical considerations are of equal importance with those which are purely chemical or mechanical.

The intervale or bottom lands of rivers are irrigated naturally by way of flowage, and it often happens that the process is allied to that of warping, inasmuch as some useful sediment is left upon the land in addition to the matters which the soil or the plants upon it may absorb from the water. It must not be forgotten, however, that the crops upon these intervale lands profit also from the underground water, which even in the driest seasons stands at a convenient height in them, not very far from the surface of the land. As has been said already, one advantage may be gained by flooding meadows early in the spring, in that the grass will begin to grow upon them earlier than it would have done otherwise.

In the rice-fields of many countries the process of flowing is often dependent upon the ebb and flow of the tide in the river from which water is derived, and at certain seasons, when the water is turbid, the process becomes one of warping more or less clearly defined. In the Italian rice-fields, on the contrary, and those of Central India also, the ground is divided into compartments, which rise one above the other in gradual succession up to the level of the canal from which the supply of water is drawn. The water that has been used to flow one flat is drawn off to flow the flat next below, and so on in succession to the lowest part of the field. In the case of this swamp plant, the main object is to give it a thorough wetting, rather than to fertilize it by means of matters which the water holds dissolved, as is the case in ordinary irrigation.

Fixation of Matter from Irrigation Water.

An interesting illustration of the power of silicates and humates in the soil to fix several of the constituents of brook-water, and of the significance of this fact as a means of explaining certain observed phenomena which were formerly incomprehensible, is afforded by the following statement of the distinguished French chemist Malaguti. It is not very many years since he wrote as follows: —

"It has been noticed in England that water which had been used to irrigate a meadow lost the half of its chloride of sodium and of its bicarbonate of lime. This observation is exceedingly curious, for it reveals a mode of action on the part of the irrigating water that was far from being suspected. It was conceivable that the water with which a field was wet would be absorbed by the roots of the plants, and that it would give up to the plants the substances which it held in solution. It is conceivable also that the carbonate of lime held dissolved in the water by virtue of carbonic acid gas would be deposited in part as the gas exhaled. But it is less easy to comprehend how the water, in passing over the field, can be deprived of a part of its common salt. It looks, indeed, as if plants were capable under certain conditions of absorbing a much larger proportion of saline matters than has been believed hitherto. But the fact, as above stated, explains perfectly why the waters used for irrigation lose their fertilizing power in proportion as their use is prolonged. Practical men express this fact by saying that the water is 'used up,' or that it is 'tired.'"

It is now known, of course, that, thanks to the reactions of the double silicates and humates contained in it, a soil may withdraw potash, magnesia, ammonia, and phosphoric acid from brook-water, i. e. precisely those substances which are most needed as food for plants; and that soda and lime may be absorbed also, as in the experiment cited by Malaguti, while they act to set free potash or some other fertilizing matter that had previously been fixed.

Moreover, the inability of the soil to retain nitrates explains how it is that water which has flowed over rich ground may be doubly valuable, in so far as this particular constituent is concerned, for the irrigation of poor land. It is known, too, that water which has been freely exposed to the atmosphere contains a certain definite amount of air, and that this air in water is much richer in oxygen than atmospheric air is. It contains, in fact, 35% of oxygen by volume, and 65% of nitrogen. Even the air in rain-water and in melted snow has the composition here stated. Rain-water often contains, moreover, noticeable quantities of peroxide of hydrogen. But within the soil the oxygen carried thither by water will quickly unite with oxidizable matters and be consumed. It follows that such introduction of oxygen dissolved in water is to be classed among the causes which work to make irrigation useful.

Waters that are fit for Use.

In view of the varying composition of natural waters, it is inevitable that the value of different kinds of water, considered as fertilizing agents, must vary exceedingly according to the kinds and amounts of matter which the waters hold dissolved. A good example of such variation is afforded by the experiments of Birner and Lucanus on growing oats, by way of water culture, in brook and well water. Among other things, 100,000 parts of the waters in question contained, —

	Nitrogen as Ammonia.	Nitrogen as Nitric Acid.	Phosph. Acid.	Potash.	Lime.	Sulph. Acid.	Magnesia.
The well-water . .	0.08	1.56	0.16	2.13	15.14	7.45	1.54
The brook-water .	0.08	0.04	0.11	0.62	7.84	1.46	0.87

The jars in which the plants were grown were recharged with water every week, one litre of water being thus supplied to each plant. An average plant weighed, dry, in the case of the well-water, 2.9190 grm. with 1.2490 grm. of grain; in that of the brook-water, 0.3112 grm. with 0.1087 grm. of grain. That is to say, the development of the plants was more vigorous in the well than in the brook water, in consonance with the larger amount of plant-food that the well-water contained. It has indeed always been recognized by practical men in all parts of the world, that, while the waters of some streams are peculiarly well fitted for irrigating, those of other streams are less valuable, or even wellnigh worthless. In cases where there is a choice between several streams, analysis would quickly show which is the best. There are various natural signs, also, that are dwelt upon by agricultural writers. Thus, when a brook is well stocked with aquatic plants, and when the stones at its bottom are covered with slime (so called), which is in reality a vegetable growth, and when the plants upon the banks of the brook grow luxuriantly, it may safely be concluded that the water is fit to be used for irrigating, since it must manifestly contain a good supply of the substances necessary for the growth of plants.

Other points to be mentioned are the influence which may be exerted by water, and carbonic acid in the water, to disintegrate fragments of rocks and minerals in the soil, and the tendency of moisture when in presence of air to cause humus to decay with improvement of its inert nitrogen. Evidently, in every system of intermittent irrigation, there must be times and seasons when the amount of moisture in the soil will be favorable for processes of fermentation, disintegration, or nitrification, as the case may be.

Irrigation with Liquid Manure.

A few words may here be said concerning an English method of applying liquid manure, which excited much attention some years ago. The idea was, instead of trying to absorb the liquid part of animal excrements with straw, or leaves, or peat, as is usual, to collect the liquid in a cistern, and even to stir up the solid dung with water, and to send the fluid to the fields through iron pipes, there to apply it by way of irrigation.

The pipes were laid down as for an ordinary aqueduct, and the diluted manure was made to flow through them to the field under such a head of pressure that it could be thrown at will upon any part of the land by means of hose attached to hydrants on the pipe. When possible, the pressure necessary to discharge the liquid in this way was got by force of gravitation, i. e. the field to be irrigated was chosen at a level considerably lower than that of the barnyard. But since this method would only be practicable on a hilly farm, several persons who adopted the system did not hesitate to set up steam pumps to drive the liquid through the pipes. Among others, Mr. Mechi, at Tiptree Hall, near London, employed steam in this way, and continued to use it until the time of his death, in 1880, while insisting that the method was a profitable one. His estate had come, however, to be a sort of show to be visited by agricultural travellers. In this case, the cattle were kept upon a grating, through which their excrements fell into a tank of water. Sometimes rape-seed cake was thrown into the tank, as in Flanders, or some other fertilizing material was employed to increase the value of the liquor. In any event, the excrements were largely diluted with water before the liquid was sent out through the pipes.

In a climate so mild as that of England, it might be possible in this way to apply all the manure to the land in the fresh condition, and so avoid the waste of nitrogen which is inevitable when masses of dung, and especially urine, are allowed to accumulate and undergo destructive fermentation.

In cases where large numbers of cows are maintained upon watery food, such as green cut clover or distillery slop, and where, consequently, much liquid manure is produced naturally, it might be specially advantageous to send this product immediately to the fields as a means of saving it. Such masses of liquid manure are notoriously difficult to manage. They are not readily to be stored, and the material is one specially apt to run to waste, and to spoil rapidly when kept. Some years ago, a German writer called attention to the fact, that the most favorable condition for adopting this system of irrigation would be a milk farm based on potato slop, roots, and green fodder. For, in this case, a large proportion of the manure will be produced in the liquid form, and no straw will be at hand to absorb the liquid. The crops, moreover, are of kinds that will bear forcing.

Many large-way farmers in Europe, recognizing the great value of liquid manure and the impossibility of keeping it, are accustomed to distribute some of it, properly diluted, upon grass-land, or to help forward a backward grain crop in the earlier stages of its growth. For this purpose, the liquid is carried out in great casks set upon wheels, similar to the watering-carts employed to lay the dust in cities. Sometimes it is used also, as in Flanders, to force gross-feeding crops, like tobacco or cabbages.

Failure of the Pipe System.

After thorough trial, continued in several instances through a long series of years, the elaborate English experiments have practically been given up, and the idea of manuring a whole farm in this way, or anything more than some favorably situated field, is now esteemed to be an impracticable notion.

The trouble lies in the original cost of establishing the system of pipes and the pumping apparatus. Professor Anderson has contrasted the cost of distributing the liquid manure at Mr. Mechi's farm with that of applying an equivalent quantity of guano, as follows. About 50,000 gallons of liquid were applied to the acre, at a cost of 4 cents per ton. This quantity of the liquid contained about 39 lb. of ammonia, or as much, perhaps, as 2 cwt. of guano. But the guano, plus the expense of spreading, cost in 1860 from $7 to $8 per acre, while the cost of distributing the liquid was more than $9 per acre.

The liquid manure was not found to be so generally applicable as guano, in the English practice. It answered an excellent purpose, however, upon grass, — particularly upon Italian ray-grass, — and did tolerably well with the other forage crops. In dry seasons, especially, the crops succeeded admirably, — the very years, of course, when the products were most valuable. So too, in early spring an abundant growth of grass could be started at the very time when the winter's store of turnips and other food was beginning to be exhausted.

With grain crops the good effects of the liquid manure were much less marked, and on the whole it was found to be not so well fitted for the general requirements of the farm as solid manure. From the first, it was recognized in England that liquid manure cannot be applied with advantage to all kinds of soils. It is not at all fitted, for example, for use upon heavy clays.

Evidently a modification of the English system might sometimes be adopted. Thus, in case there was only a moderate fall between the barnyard and the field to be irrigated, the liquid manure might still be made to flow by force of gravity into a tank in the field, whence it could be thrown about in all directions by means of a force-pump or a garden engine, or it might be distributed with buckets. For an arrangement such as this, bored logs might be substituted for the iron pipes, in some localities.

It is conceivable that, with inexpensive apparatus such as this, it may sometimes be advantageous to set apart a single field to receive the excess of liquid manure from the barnyard and the kitchen sink in cases where tobacco can be grown, or merchantable vegetables, or perhaps even in cases where fodder corn could be forced for feeding cows. Many a small sloping field might be well manured by occasionally pumping, with steam or horse power, the contents of a barnyard cistern into an open ditch or ditches running across the field. Either this work would be done at a time of rain, or the original liquid manure would be diluted with much water, as in all such cases of flowage. The diluted dung liquor of the English plan was a very different and a much weaker product than barnyard liquor or than urine.

A remarkable mixed system of manuring and watering has been practised in Belgium in a sandy region known as the Campine. The system consisted in irrigating the barren grass-land with canal-water during the autumn, and again in the spring until April, when the grass was gone over with a stiff brush harrow, and a dressing of 100 lb. of guano to the acre was applied to it. After the application of the guano, the supply of water is shut off for a fortnight, and subsequently the water is only let on occasionally during the growth of the grass, i.e. as often as the ground becomes somewhat dry. Since the ground lies low, and is full of ditches, there is no need of frequent irrigation. After the grass has been mown, another dressing of 25 lb. guano to the acre is applied.

CHAPTER XV.

SEWAGE.

The question how best to dispose of the sewage of cities is one of great general interest and importance, concerning which much might be said. Indeed, few questions relating to agriculture have been more frequently discussed in recent years than this one, and upon none have discordant views been urged more emphatically.

It has become customary and fashionable for magazine writers to bewail the wasteful habits of civilized men, and to lament the vast quantities of fertilizing materials which, as they say, are unnecessarily lost to agriculture when sewers are made to flow into the sea; and a great variety of people have joined in this cry, from Baron Liebig in the scientific journals to Victor Hugo in his novels. The matter has been discussed from many points of view, moreover. To some minds the question presents itself as one of conscience or morality, for others it is a question of political economy, while to many persons it is a matter of sentiment pure and simple. Few, if any, practical farmers have been able to perceive that the question has any general or important bearing upon agriculture.

In reality, the problem how to dispose of the sewage of a city is simply a sanitary question. First and last, the subject relates to the health and comfort of the citizens; and it needs to be clearly understood that neither agriculture nor political economy has any concern as to what shall be done with the filth of cities, until all sanitary requirements have been fulfilled, effectively and economically.

A single sentence, quoted almost at random, will show the general drift of the sentimental feeling just now referred to. It was written some years since, as expressing the views of the famous German chemist Liebig, whose eloquence and enthusiasm often enough carried him far beyond the bounds of sense and sobriety.

"England," he exclaims, "is robbing all other countries of the conditions of their fertility. Already, in her eagerness for bones, she has turned up the battle-fields of Leipsic, of Waterloo, and of the Crimea; already from the catacombs of Sicily she has carried away the skeletons of many generations of men. Annually she removes from the shores of other countries to her own the manurial equivalent of three millions and a half of men; she takes from us the means of supporting them, and squanders it down her sewers to the sea. Like a vampire she hangs upon the neck of Europe, — nay, of the entire world, — and sucks the heart-blood from nations, without a thought of justice toward them, — without a shadow of lasting advantage for herself."

"It is impossible," he goes on to say, "that such iniquitous interference with the Divine order of the world should escape its rightful punishment; and this may, perhaps, overtake England even sooner than the countries she robs. Most assuredly a time awaits her when all her riches of gold, iron, and coal will be inadequate to buy back a thousandth part of the conditions of life which for centuries she has wantonly squandered away."

Considered as a mere matter of reasoning, the fallacy of such talk as this can easily be shown; but the feeling or sentiment which the citation illustrates is endowed with perennial vigor, and can probably never be composed.

It is true, no doubt, that, as a result of the circulation of phosphoric acid, of potash, of nitrogen, lime, etc., out of the earth through plants and animals to man, enormous quantities of these matters do go to waste under the existing conditions of civilized life, particularly wherever large numbers of men are congregated. It is true, moreover, that it is easy to conceive of a closed and close circuit, as it were, in which these elements of plant-food should be returned from man directly to the soil whence they were originally derived; and there is seen, in fact, in China, Japan, and Belgium, a tolerably close realization in practice of this theoretical conception. But, to say nothing for the moment of the enormous risks to health which lurk in human excrements, it is also true that every farmer, in these days of safe and easy communication, at least every farmer who lives within the limit of influence of a great city, or within reach of railways or steamboats, has the whole world from which to draw his supplies of manure. He can get the phosphoric acid needed by his crops from Spain, Canada, Norway, and Spitzbergen, from the coprolite beds of England, France, and Germany, or from the phosphatic deposits of the Carolinas and the Caribbean Sea. Nitrogen he can have in abundance from the gas-works of cities and from coke furnaces, from the nitre beds of Peru, and from the refuse of fish, flesh, and oily seeds; while of potash there is an inexhaustible store at Stassfurt.

Commercial Fertilizers better than Sewage.

So long as the supply of artificial fertilizers remains abundant, the farmer is virtually independent of the sewage of his city. Indeed, he cannot afford to think of using the sewage, unless it can be supplied to him at less cost of money and labor than would suffice to bring to him a corresponding supply of fertilizers from abroad.

Weakness of Sewage.

A ton of sewage, such as is produced in European cities that are provided with aqueducts and water-closets, ordinarily contains some 2 or 3 lb. of total dry matter. In American cities the amount of dry matter in sewage is still lower. Prof. W. R. Nichols found less than 2 lb. of it to more than 1,998 lb. of water in Boston sewage in 1872; and about 1 lb. to the ton in the sewage of Worcester, Massachusetts.

With regard to the variations which may occur in sewage from week to week, accordingly as the weather is or is not rainy, Lawes and Gilbert have made the following statement of the highest and lowest number of pounds (avoirdupois) of total dry matter found in the long ton of Rugby sewage.

	24 Tests, April, 1861, to Nov., 1861.	34 Tests, Nov., 1861, to Oct., 1862.	35 Tests, Nov., 1862, to Oct., 1863.
Largest amount	6.93	4.14	3.64
Smallest amount	1.20	1.62	1.99
Means	2.41	2.57	3.30

The amount of matter actually in solution in the Rugby sewage, and of that in suspension also, will appear from the following table, which gives the mean results of all the (93) analyses above mentioned, in pounds (avoirdupois), in a long ton of English sewage.

	Dissolved Matter.	Suspended Matter.	Total Dry Matter.
Organic	0.276	0.603	0.879
Inorganic	1.146	0.778	1.924
Sum	1.422	1.381	2.803
In 2,000 lb. Boston sewage . .	1.179	0.747	1.926
In 2,000 lb. Worcester sewage .	0.507	0.423	0.930
In 2,000 lb. Berlin sewage . .	1.578	0.102	1.680
In 2,000 lb. Dantzic sewage . .	1.366	1.164	2.530
In 2,000 lb. of sewage, average of 50 English towns	1.444	0.894	2.338

Of the fertilizing matters in sewage, the nitrogen compounds are by far the most important, but the amount of them is very small. More or less of the nitrogen will naturally be in the form of urea, or of ammonia, according as the sewage is fresh or old. In any event, moreover, a considerable part of the nitrogen will always be in the form of inert organic compounds other than urea.

Letheby gives the average amount of nitrogen in the sewage of English towns as 0.178 lb. to the ton. Lawes and Gilbert have noted that the average of many analyses of London sewage gives 0.206 lb. of ammonia to the ton; as the mean of 93 analyses of Rugby sewage, they found 0.185 lb. of ammonia to the ton. The average of 50 English towns is said to be 0.155 lb. of total nitrogen to the ton of sewage. In this case ammonia was given as 0.134 lb., and 0.044 lb. of the nitrogen was said to be in organic combination. Traces of nitrates are commonly observed.

The sewage of Dantzic, in Germany, is said to carry 0.13 lb. of total nitrogen to the ton, 0.023 lb. being in organic combination. The amount of ammonia is stated as 0.129 lb. to the ton. In Boston and Worcester sewage Nichols found 0.054 lb. and 0.038 lb. of ammonia, respectively, beside traces of nitrates.

As for phosphoric acid, 0.034, 0.032, 0.007, and 0.003 lb. of it to the ton of sewage has been found in Boston, Berlin, Worcester, and Dantzic, respectively. Letheby puts it as high as 0.045 lb. for the average of English towns; and potash he rates at 0.048 lb. to the ton of sewage.

From data such as these it has been estimated that the sewage of English cities may contain in every ton from 1 to 4 cents' worth of fertilizing matters.

A ton of the Boston sewage above mentioned may perhaps have contained a cent's worth of plant-food; or, speaking more precisely, 400,000 parts of this sewage contained some 11 parts of ammonia and nitrates, which is about as much as would be contained in 100 lb. of really good Peruvian guano, and less than 7 parts of phosphoric acid, or little more than half as much as the 100 lb. of guano would contain. Since the sewers of a city carry off vast quantities of rain-water, as well as all the water that is delivered by house-drains, it is evident that in regions where the rainfall is large, as well as in cities that are abundantly supplied with aqueduct water, the sewage will be specially worthless.

In some American cities the average consumption of water for each individual inhabitant amounts to 100 gallons or more daily; and, in so far as concerns the present argument, it is no matter that much of this water is "wasted," for practically a very large part of it goes into the sewers, to the great advantage of the public health it should be said. Since the average rainfall and the average water supply in American cities are about twice as large as in most English and German towns, American sewage will naturally be more dilute than that of Europe.

The economic Argument against Manuring with Sewage.

To illustrate the poverty of sewage in respect to fertilizing ingredients, it may be urged, as a self-evident proposition, that any man would be foolish if, wishing to apply lime to his fields, he should insist on doing so through the intervention of sewage, although sewage does contain a certain small proportion of lime compounds. Way, for example, found from 0.04 to 0.07 lb. of lime to the ton in London sewage. In point of fact, when the farmer wants lime he buys it for a song in the shape of quicklime or of leached ashes, or in the form of waste lime from soap- or gas-works, or as gypsum even, and takes no further trouble. But in precisely the same way he can buy phosphoric acid and nitrogen and potash, as well as lime; and by the simplest rules of business he is bound to obtain these things wherever they can be had at the best advantage.

As Professor Anderson suggested long ago, it would be about as reasonable to expect the farmers to manure their land with the smoke of cities as with sewage; for, as every one knows, enormous quantities of ammonia must be lost in the aggregate from cities where domestic fires are fed with soft coal. But precisely as it is with smoke, so is it with sewage; that is to say, the fluid is so very dilute that it cannot be put to use.

The geologist David Forbes also, in replying to calculations based upon the assumption that the excrements of each inhabitant of a city represent a value of several dollars a year, argued that it would be equally correct to maintain that a barrel of water into which a bottle of brandy had been poured would be worth as much as the original brandy. Most of the alcohol could indeed be recovered from the water by distillation, but at a cost far greater than its value; and so it has proved to be with sewage whenever attempts have been made to extract the fertilizing matters that are contained in it.

No matter how freely it may be admitted that immense quantities of plant-food are carried out from a city every year through the sewers, it remains none the less true that these fertilizing matters are carried out in a state of such extreme dilution that it is idle to talk of recovering any of them economically in the present conditions of labor and commerce, or of utilizing the sewage in any way excepting in some rare localities, as at Edinburgh and Milan, where circumstances permit of its being applied directly for purposes of irrigation.

There are many other familiar instances of valuable matters to be found at our very doors, so diluted that they are not worth the cost of collecting or saving. From the experiments of Eckfeldt and Dubois of the United States Mint at Philadelphia, it appears that beneath the paved portion of that city there is an extensive bed of clay which contains a pound of gold for every 1,224,000 lb. of clay. In every cart-load of clay hauled out in excavating the cellars of Philadelphia there is concealed as much gold as would be sufficient to pay for the carting. If the bricks that front the houses in that city could have their contents of gold brought to the surface in the form of gold-leaf, there would be a glittering patch of two square inches upon every brick.

In that portion of the clay bed that lies beneath the streets and houses of Philadelphia there are some 126 millions of dollars' worth of gold, and it is safe to assume that there are eight times as much of the clay within the corporate limits of the city. But, excepting as a matter of scientific interest, no one has ever dreamed of extracting gold from the Philadelphia clay. It would be folly to think of extracting it so long as gold can be got with infinitely less trouble from places where it is more abundant. Of course here, as everywhere else, the cost of getting the thing depends on the amount of labor that must be expended; and, in the present condition of things, labor can be expended to so much better advantage in ten thousand other ways that no one can afford to extract this gold.

Some old gold washings on the river Rhine afford an analogous example. Certain gold-bearing sands occur there which carry so much gold that it is almost, but not quite, worth while to work for it in ordinary seasons. But in times when the price of labor has been exceptionally low, that is to say, when, from the partial failure of crops, there was unusually little work to be done, and there were more laborers in the region than could find occupation, it has happened that the unemployed men have turned their attention to gold washing, and have in that way made shift to keep body and soul together. Something similar is seen at many exhausted gold washings in California, where, in anticipation of special holidays, or the advent of some wandering show, the village boys are accustomed to wash out gold dust enough from the waste gravel to enable them fully to enjoy the occasion.

There is no need, however, to go outside the domain of agriculture to seek for such examples. So long as there is inert nitrogen in coal, from which ammonia might be had at no very great cost if we cared to extract it, it is idle to talk of the "irreparable" waste of nitrogen in sewage. Such talk was simply foolish so long as the gases distilled from coke furnaces were permitted to escape unchecked into the air, as they are indeed even now in many places. It is safe to say, for that matter, that when there is no more fish-scrap to be had from the sea, and that when the stock of nitrogen in peat is exhausted, then the ammonia from coke furnaces will be collected everywhere with scrupulous care, and that obtainable from leather scrap also. Such sources of ammonia as these will undoubtedly take precedence of the nitrogen in sewage.

So, too, when the mine at Stassfurt shall perchance show signs of failing, there will still be, as before, unlimited supplies of potash in the granitic rocks which are found pretty generally diffused on the face of the earth; and it will undoubtedly be found more convenient then, as now, to extract potash from such rocks, than to get it out of sewage. It will undoubtedly be found still cheaper then, as now, to let plants get the potash out of the rocks, and then take it from the plants, as has been the custom hitherto.

How was it with respect to potash formerly, before the discovery of the Stassfurt mine? Why, it was actually at one time an agricultural product; i. e. it was a crop, in the strictest sense of the word; and it is so still perhaps in some places, though the working of the Stassfurt mine, which upon the whole has been a great boon to agriculture, has interfered very decidedly with the tolerably large class of husbandmen who depended for their livelihood upon the making of potashes.

Wood is so abundant and unmerchantable in several thinly populated countries, as at the North of Europe as well as in some parts of Canada and of our own country, that the only way of deriving profit from it was to burn it solely for the sake of the ashes. The same remark was true formerly of straw and weeds in some parts of Russia, and it was true also at one time of brushwood and the trimmings of logs in Germany, for potashes were a highly important product previous to the invention of an economic process for making soda ash from common salt, and the substitution of this alkali for the more costly potash compound.

There can be no question as to the propriety of the old custom of burning wood merely for the sake of its potash in those comparatively speaking inaccessible places which were unfit for the more profitable operations of agriculture. It is a simple question of getting an honest living as easily as possible. In some places cotton is the proper crop, in some wheat, in others corn, in some hay, and in others potash. This is all that can be said about it; and so long as potash can be had in this way more cheaply and conveniently than it can be had from human excrements, it is truly absurd to lament the sending of sewage potash to the sea. In the case of the forest wood the continual disintegration of the soil keeps up a sufficient supply of potash, so that the potash husbandry now in question might be carried on for an indefinite period. The idea of completely exhausting a soil in this way is not to be entertained, since the supply of wood is practically unlimited, and the potash farmer must of necessity allow as much time as is required for the new wood to grow.

It has been calculated that a single cubic foot of feldspar is sufficient to supply an oak wood covering a surface of 26,910 square feet with potash for five years. As has been said before, it is customary in the vicinity of Boston to take repeated crops of hard wood from poor gravelly soils every 15, or 20, or 30 years, and there is not the least prospect of the soils becoming exhausted. There are withal several other large deposits of potash known in the world beside the one at Stassfurt. The Dead Sea also is capable of supplying enormous quantities of potash salts, as well as of chloride of sodium.

The risk that the present abundant supplies of phosphoric acid may give out is hardly any greater than the risk that nitrogen or potash may fail. Several important deposits of phosphates have been discovered in recent years, and large quantities of impure phosphates, not rich enough to be mined at present prices, are known to exist. Twenty or thirty years ago greater uneasiness was felt in respect to the continuance of abundant supplies of phosphates than would now be justified. Indeed, the price of phosphoric acid, which rose decidedly shortly after the middle of this century, now tends to remain tolerably constant and moderate, in spite of the enormously increased use of phosphatic fertilizers.

The discovery of the rock phosphates of South Carolina and of the apatite of Canada has undoubtedly had a very great influence in checking the rise in price of all kinds of phosphates. Moreover, there are enormous masses of phosphates in Spain, and in many other localities, which, though still rather inaccessible, will doubtless be drawn upon more freely in times of future need. Nowadays some small quantities of phosphates are recovered in the form of fish and flesh scrap, and in wood ashes, and it may perhaps be true that, if worse came to worst, merchantable supplies of phosphoric acid might be had from these things more conveniently than from sewage.

Meanwhile, it is a highly interesting fact, that at the South Carolina phosphate beds the laborers dig no deeper than ten feet from the surface of the land. So long as the price obtainable for the mineral is no higher than it is now, it does not pay to dig for it any deeper than ten feet, unless the nodules happen to be of very superior quality. (Penrose.)

It is consoling to reflect, withal, that in case the supply of mineral phosphates should give out some day, and it should then be found impracticable to get enough phosphoric acid from fish and from sea and land plants, there would still be the city filth to fall back upon. For it is a peculiarity of the case, which some writers seem to have overlooked, that just as much of phosphoric acid and of the other fertilizers will be excreted in the future as now, so long as men are constituted as they are, and so long as they are as well fed. Whenever it shall be found advantageous to begin to save these matters, posterity will be in no single particular less favorably situated for doing so than we are now.

Manifestly, then, it is the part of wisdom to have the fertility of farms kept up by means of manures that have been obtained in the most economical manner possible, no matter whence these manures have been derived. It will be time enough to begin to utilize sewage and night-soil when circumstances shall indicate the economy of so doing. There is need, meanwhile, that every instructed person should do what he can towards discountenancing the absurd view that the sewage of cities "belongs" to the land. This idea has done infinite harm already, by hindering municipal authorities from establishing proper systems of sewage, such as the health of the inhabitants demands. It would be well, withal, for every one to understand that, when the farmers really want the filth of cities, they will find means of getting it. They will speedily take measures for informing the citizens of their desires.

"Waste" of Fertilizers by Rivers.

There are other considerations besides those just now urged which go to show the absurdity of the cry that the great cities are wasting the fat of the earth through their sewers into the sea. Look at all the rivers in the world. What goes to waste through them? Consider the supply of phosphoric acid from which wild plants get what they need. It comes manifestly from the decomposition of rocks by the action of carbonic acid, air, and water, and other chemical agents. But beside going into plants, some part of these highly dilute solutions of phosphoric acid, and of the other elements of plant food as well, are all the while slowly leaching out of the soil into the brooks and rivers, and so into the sea. The mere fact that aquatic plants grow in the waters shows the presence of phosphoric acid there plainly enough.

It is true, of course, that the absorptive power of the soil works against the escape of phosphoric acid from the land, but it is powerless to prevent it entirely. This waste goes on incessantly by day and by night, as it has gone on since the beginning of time, and the aggregate amount of material thus transported by even a single one of the large rivers must be simply stupendous.

Perhaps there is more phosphoric acid thrown out in this way naturally into the sea in a single day than would be discharged in a century by all the sewers in the world. So, too, with nitrogen. Boussingault has shown that the river Rhine carries to sea every day an amount of nitric acid equivalent to 220 tons of saltpetre. The Seine carries out 270 tons, and the Nile 1,100 tons.

It needs no careful calculation to show that the amounts of phosphoric acid and of nitrates carried off artificially in the sewers must be wellnigh insignificant, in comparison with that which goes to sea naturally every hour, through rivers all over the globe. Precisely in the same sense that it would be foolish to try to collect these fertilizers from the river water in cases where they could be had at less cost from sewage, so is it foolish to think of getting them from sewage when they can be got at still better advantage from fish and sea plants, and from minerals taken from the earth.

Harlacher and Breitenlohner have drawn up an interesting statement as to the amounts of inorganic plant-food that are carried out of Bohemia every year in the water of the river Elbe. All the brooks and rivers of Bohemia flow into the Elbe, and it was a comparatively easy matter to analyze the water of this river repeatedly, and to determine the rate and amount of its flow; since there were 72 stations for rain-gauges in the country, the average rainfall was well known. It appeared that only about one fourth of the yearly rainfall in Bohemia flowed out through the river. The other three fourths either evaporate into the air in various ways, or soak out of the country as ground water. Actually five billion cubic metres of water flow past the town of Lobositz in a year, and this water contains, in terms of millions of kilograms: —

	Solid.	Volatile.	Total.
Dissolved matters	401.65	117.25	518.90
Suspended matters	413.10	42.85	455.95
	814.75	160.10	974.85

Moreover, the five billion cubic metres of water contain the following amounts of ash ingredients, stated in terms of millions of kilograms.

	Suspended.	Dissolved.	Total.
Lime	2.48	114.50	116.98
Magnesia	1.44	22.00	23.44
Potash	20.28	25.15	45.43
Soda	4.55	28.45	33.00
Chloride of sodium	...	21.10	21.10
Sulphuric acid	0.28	37.85	38.13
Phosphoric acid	1.25	trace.	1.25
	30.28	249.05	279.33

That is to say, 89% of dissolved, and 11% of suspended matters. Since a kilogram is equal to 2.2 lb., it appears that of phosphoric acid alone 2¾ millions of pounds are carried off every year in the river water.

Modern Improvements.

It is idle to assert, as has been done far too often, that the sewage of a city like London carries away every year several millions of dollars' worth of fertilizing materials, so long as the stubborn fact remains that very large amounts in terms of life also, as well as in terms of treasure, would have to be expended in order to collect the fertilizing matters and bring them into forms available for agricultural use. From the sanitary point of view, nothing can be more important for the health of the citizens than that all excremental matters shall be sent out of town as speedily as may be possible. And the best means yet invented for accomplishing this purpose is to float them out in a great volume of water.

Instead of the stagnant and leaky vaults and cesspools of former days, quick-flowing drains have been substituted, in which the filth is still further diluted with all the water that is used in the city, and much of that which falls as rain. This last may either enter the sewers through the sluiceways in the streets, or it may soak in through cracks as ground-water, much in the same way that ground-water enters an agricultural drain.

With the introduction of the water-closet and the establishment of sewers proper for its use, all stagnant collections of putrescent matter in and about houses may be done away with. By means of the swift gush of water in the closet, the filth, while still fresh, is washed out of the house into the street sewer, while the gases of the sewer are (or ought to be) prevented from passing back into the house by means of a column of water, the so-called trap, held permanently in the pipe which leads to the sewer. If the sewer have proper air vents, so that there shall be no undue pressure upon the trap, the house is safe; that is to say, it is safe if the plumbers have done their work properly, and have not led a parcel of other pipes from bath-tubs and wash-basins into the water-closet trap.

It is manifest that sewers and water-closets must have very great merit as means for cleaning cities, if only there can be found outside the city some place where the contents of the sewers may be discharged without harm. Wherever the sea is within reach, or a great river, the sewage will naturally be discharged into it, with proper precautions, and so happily be got rid of. But with respect to inland cities the problem is far less simple, and many difficulties have been encountered in disposing of the sewage of such places ever since the use of water-closets has become customary. Sewers cannot long be permitted to flow into small rivers, since the water is soon polluted, and made extremely offensive, and even dangerous to health. Hence many efforts have been made to purify sewage, either by means of filters or by chemical precipitants, by irrigation, or by soakage.

Purification of Sewage by Percolation.

Of the several plans above mentioned, the last named has approved itself to be commonly the best and the cheapest. It is evidently more generally applicable than either of the other methods. Mere "filters," i. e. filter-beds, whether of sand, gravel, or charcoal, such as are used for clarifying river-water, are of very little use in respect to sewage. They soon become clogged and impervious to the passage of the liquid, and even at the first they only stop the suspended mud, but not the matters that are actually dissolved in the water. To bring about the fixation of odors, coloring matters, and dissolved organic matters, to say nothing of ammonia and phosphates, the sewage needs to come into contact with great masses of earth, as when it is made to soak into a field.

As regards "germs," and microscopic organisms of whatever name, which may be contained in the sewage, many of them will be strained out mechanically by the earth, as by any close filter; and some of them will be destroyed, no doubt, in the earth, by the ordinary microdemes which are contained in it, especially in the upper layers. It is not improbable that some of the most dangerous germs, such as might infect or poison drinking-water by making it a vehicle for the transmission of specific diseases, may be killed in this way by the organisms naturally present in moist earth and in other decaying organic matters.

Intermittent Filtration.

It is a well-known fact, that, when earth which has been soaked and saturated with sewage is exposed to the free action of air, many of the matters which have been absorbed by the earth are oxidized and destroyed. Undoubtedly, this destruction depends largely, perhaps chiefly, on fermentations due to the presence of microscopic organisms in the earth, which require access to air in order to their best action. Hence the value of "intermittent filtration," i. e. of alternately soaking and aerating the soil. Practically, a number of acres of loose and open soil are underlaid with tile drains, at a depth of 6 or 8 or 10 or 12 feet, and the sewage is made to soak at intervals through one or another part of the field. The idea is, that the whole of the foul liquid shall soak down into and through the soil, instead of flowing over it in good part, as happens in ordinary irrigation.

One instance has been reported, for example, where the sewage from a town of 40,000 inhabitants was disposed of on a field of

20 acres, which had been divided into four plots of equal size. The sewage was made to flow upon each of the plots for 6 hours at a time, and the land was then left at rest for 18 hours for aeration. Before coming to the land, the sewage passes through a strainer to remove the coarser suspended matters, and is then either made to flow out upon the surface of the land, or through drain tiles concealed beneath the surface. Sometimes ray-grass has been grown on the surface of such filtering fields, and this grass has been found capable of supporting enormous quantities of sewage in such situations.

In the instance here cited, the soil was a light loam upon a deep gravelly subsoil. Under such conditions, it is said that the filtrate from the sewage flows out from the land to all appearance as clear and clean as ground-water usually is. Since only a comparatively small area of land is needed for putting this system in practice, it possesses an enormous advantage over methods in which the sewage is purified by methods of irrigation properly so called. It has been claimed that some soils can clarify sewage in this way at the rate of 100,000 gallons to the acre per diem.

That mere continuous percolation of sewage through earth may often be ineffective as a means of removing or destroying disease germs, is evident enough from experience relating to the infection of well-waters by leaky cesspools. In such cases the sewage has commonly flowed laterally through a non-aerated subsoil.

Purification of Sewage by Ferments.

The influence of microdemes in purifying sewage is so distinct and important, that Alexander Müller has sought to systematize it and put it to practical use. He has devised a process, specially applicable no doubt to cases where no very large amounts of liquid have to be dealt with, which seems well adapted for purifying the drain-water from a country house, or that from certain factories, as those where beet sugar is made. The idea is simply to foster, or even cultivate systematically in the sewage, organisms which shall feed upon the matters which might become offensive or dangerous if they were left to themselves. To this end, care must be taken to make the sewage neutral; to maintain it at a suitable temperature, i. e. to prevent it from cooling unduly; and to provide a complete supply of food for the desired organisms, by adding to the liquid, if need be, such ash ingredients as may be required to supplement those already contained in it. The original intention was to "seed" the sewage by adding to it a quantity of the chosen ferment, much in the same way that yeast is used in bread-making; but practically it has been found that, during summer at least, this particular step is unnecessary, since an abundant supply of germs fall into the liquid from the air, and develop there freely if it is in a fit condition for their support.

Purifying Power of Earth.

It is of interest to note that the power of the surface soil to absorb, and hold, and destroy foul odors has really been put to use by men from the earliest times, and that the modern application of it to a matter so dilute as sewage is a mere modification of the method of burying which has so long been customary. Naturally enough, different kinds of soils vary considerably in respect to their power of purifying sewage. But it has been noticed in England, that even "slow soakage through a few feet of gravel destroys more organic matter than does a flow of many miles in the Thames." For that matter, it is now recognized that the natural purification of river-water, after sewage has been mixed with it, is a much slower process than was formerly supposed.

From experiments made by the English Commissioners, it appeared, that, while a soil from Dursley that contained 18% of oxide of iron and 43% of silica purified sewage at the rate of 9.9 gallons per cubic yard per day, few soils could be found so good as this. A soil that will purify 8 gallons per cubic yard per day would be regarded as excellent. In case the field carried tile drains at a depth of 6 feet, there would be 9,680 cubic yards of filtering material to the acre; and at 8 gallons to the yard, the acre would purify 77,440 gallons. The Commissioners held that in laying out a filtering field there should be allowed one cubic yard of soil for 5½ gallons of sewage. They found that under these conditions the organic carbon in 100,000 parts of sewage was reduced from 4.386 parts to 0.734 part, and the organic nitrogen from 2.484 to 0.108, and that the whole of the suspended matter was removed. Nitrates and nitrites were found in the effluent water, though not detected in the sewage previous to filtration. Of other soils experimented upon, one from Beddington purified sewage at the rate of 7.6 gallons per cubic yard per day, and exhibited a remarkable power of nitrification. But on doubling the amount of sewage, nitrification ceased, and the soil became clogged. A soil from Hambrook purified no more than 4.4 gallons per day, one from Barking 3.8 gallons, and peat 4 gallons.

In so far as nitrification is concerned, Alexander Müller has noticed that, when temperature and other conditions are favorable, the ammonia in diluted urine changes rapidly to nitrates, but that a diluted mixture of urine and solid excrement is much less subject to nitrification, perhaps because some of the offensive products of the putrefaction of fæces may be inimical to the life of the ferment. This observation goes far to explain a fact which has often been noticed; viz. that the waters of brooks into which mere urine has been poured clarify themselves much more quickly than do those which have received a quantity of night-soil.

Purification by Irrigation.

As has been said already (page 267), it occasionally happens that sewage may be usefully applied for purposes of irrigation, particularly where waste land lies near at hand, and there are no neighbors to inconvenience. The process has undoubted merit, when circumstances permit of its being applied with economy.

What has just been said of the purification of sewage by filtration through earth will indicate, in some measure, both the merits and the limitations of the system of irrigation; for in one sense the latter is little more than a vague and incomplete process of filtration, though it is true, no doubt, that, in addition to the action of the soil and the air, the grass or other crop on the irrigated land, and the microdemes which live there, exert a powerful purifying influence.

Even when nothing more is done to foul sewage than to make it flow over a mere grass field, as at Edinburgh, many of its impurities will soak into the earth, or be absorbed by the plant roots, or be destroyed by the microdemes in and upon the soil, and the liquid will be purified in a corresponding degree. But when, as happens in the best modern practice, the land is specially prepared beforehand for the irrigation, by laying down frequent tile drains throughout its length and breadth, it becomes a filtering field of considerable efficiency, through which large quantities of water must necessarily flow.

Percolation cheaper than Irrigation.

Considered as devices for purifying sewage, filtering fields are superior to irrigated fields, merely because an acre of land arranged for intermittent filtration is competent to clarify a much larger quantity of sewage than can be clarified by an acre of irrigated land. The first thing to be considered always is the complete purification of the sewage, at (second) the lowest possible cost. But the system of irrigation always requires much land, in order that purification may be complete; and the presence of crops upon the land other than ray-grass is in some measure antagonistic to the free application of the sewage. That is to say, unless an extravagantly large area of land was available, strict justice would require the sewage to be put upon the fields at times when it could do no good to the crops, and even when it would be certain to harm them. Herein lies an evident danger, since the grower of the crops might sometimes wish to favor them at the risk of slighting his first duty of thoroughly purifying the sewage.

Both in establishing farms of irrigation and fields for filtration, it is essential that the engineers should take care that neighboring fields and farms are not drowned out by the ground-water which soaks out from the irrigated land, or which may be backed up behind it, as it were, through disturbance of the original course of percolation of the waters natural to the soil and the locality.

Amount of Land required to clarify Sewage.

It has frequently been argued in England that, in order to dispose of sewage by way of irrigation, there will be required one acre of land, i. e. a square 70 yards to the side, for every 100 persons, and that the acre would purify 2,000 gallons of sewage per diem. Others have held that one acre will be needed for 150 persons, though on one of the most successful sewage farms in England there is an acre of land for the sewage of 60 persons.

The argument in favor of the number 100 appears to depend upon the dicta of men of experience, that an annual application of 5,000 tons of sewage to the acre gives the best practical results. In any event, this matter must be largely influenced by the climate, the character of the soil, and the amount of the rainfall, in any given locality. Thus, on the sand dunes at Dantzic, one acre is deemed to be sufficient for purifying the sewage of 600 persons; and at Berlin, 750 acres are thought to be competent to deal with the sewage of the whole population, 750,000, though the purification of the water there is far from being complete. More land will naturally be required to purify crude sewage than would be needed in case the sewage is first subjected to a process of treatment for removing the suspended matters, for the liquor thus clarified will be much less apt than the original sewage to clog the soil and silt up its pores. At an irrigation farm at Barking, there were applied during one year 622,324 tons of sewage to almost 163 acres, i. e. about 3,800 tons to the acre. During another year the average quantity was 3,342 tons to the acre. On the most porous part of the farm as much as 960 tons have been applied in twelve hours.

On the basis that an acre of land is needed for each 100 of population, Wallace calculated, in 1881, that fully 10 square miles of land would be required in order to dispose of the sewage of Glasgow and its immediate suburbs by way of irrigation; or some 12 square miles, if the neighboring burghs were included.

Precipitation with Chemicals.

Many attempts have been made to purify sewage by adding to it chemical substances which should precipitate one or another of its constituents, and it was thought at one time that some matters of agricultural value might perhaps be saved from the sewage in this way. But nowadays the most that is hoped for is that the foul liquid may be sufficiently clarified by the chemicals to permit of its being allowed to flow into brooks, or small rivers, with a minimum of filtration through earth.

As has been shown under the head of night-soil, no system of evaporating sewage to save the whole of the fertilizing matters, or of distilling it to save ammonia, can be thought of, because of their cost. But there are several methods, which depend on the use of precipitants that have been found to possess some slight practical merit, though none of them have fulfilled the expectations of their inventors. It has been found possible, for example, to clarify by means of precipitants small quantities of sewage, such as might come from a prison, or a hospital, and it is practicable also to purify in this way waste liquors from various kinds of manufacturing establishments. But none of the chemical methods have proved competent to deal with great masses of sewage, such as are poured out from a large city, except, indeed, that precipitation may sometimes serve as an ameliorant, or useful forerunner, to take out a good part of the impurities of the sewage, and so prepare it for subsequent thorough purification by processes of filtration through earth, or of irrigation.

One difficulty is, that all processes of precipitation are rather costly to begin with, since a considerable outlay has to be made on account of the establishment in which the sewage is manipulated; the work needs to be done carefully and with intelligence, and at the best it is no easy matter to avoid stenches which are highly offensive to the neighborhood. There is a constant outlay, moreover, for chemicals, and no proper outgo can be found for the products of the precipitation, which collect as black muds, or sludges, of very slight agricultural value.

Generally speaking, sewage thus clarified by chemicals still needs to be filtered through earth before it can be turned into streams whose water is employed for domestic purposes; though, as compared with the original sewage, the clarified liquor needs but little filtration, and in many places it can be discharged without any filtration at all. Several of the methods depending on precipitation are both interesting and instructive from the chemical point of view, as may be seen from the following statements concerning them.

The Lime Process.

On mixing a small quantity of milk of lime with sewage, as it flows out from a city, a light, flocculent precipitate forms; and on allowing the mixture to stand for several hours in a settling tank, the precipitate will subside and carry down with it all the insoluble matters that were suspended in the sewage, together with about one quarter of the matters that were held in solution in the sewage. Not only is some phosphoric acid thus thrown down, but soluble nitrogenized organic matters also.

The action of the lime depends in part, no doubt, on its power of coagulating or flocculating the matters suspended in the sewage, in the manner explained under the heads of Lime and Tillage. But it is also true that the lime combines with dissolved organic matters to form insoluble compounds, which envelop and entangle the finely divided suspended particles as they cohere and subside with them to form a soft, black mud of rather unpleasant odor. Meanwhile, more or less ammonia gas is set free by the action of the lime on ammonium salts in the sewage, and this ammonia acts as a vehicle to carry noxious odors into the air.

With regard to the union of lime with the soluble organic compounds, it would appear that the reaction is similar to that which occurs in the clarification of the juices of the sugar-cane and beetroot, when lime is made to combine with the analogous substances which are contained in those juices. However this may be, it is certain that the insoluble compounds that are produced when lime is added to sewage form a sort of network, which, in slowly sinking to the bottom of the tank, envelops and carries down with it

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most of the particles of solid matter which were contained in the sewage, so that the liquor is left tolerably clear, and fit to be run off into a river that is large enough to admit of the liquids being speedily mixed with a great excess of water.

In spite of its appearance, the clear liquid is in reality far from being pure. It still contains some sulphuretted hydrogen, and so large a proportion of dissolved organic matters that it speedily ferments when left to itself, and becomes highly offensive. It needs to be diluted at once with a great volume of flowing water, or to be purified by filtration through earth, or by irrigation. It has not been found practicable to help matters much by adding chemical disinfectants to this liquid.

Many difficulties have been encountered in England in trying to dispose of the sludge, i. e. the muddy precipitate which results from the addition of lime to sewage. It contains a considerable quantity of sulphide of calcium, which decomposes readily during the process of drying, with evolution of sulphuretted hydrogen. When spread upon the surface of the land, the peculiar character of the mud so hindered it from drying in that moist climate, that several months were required in order that it should become dry enough to be moved. Meanwhile, very unpleasant odors arose from the field in case the collection of mud was at all large.

According to Wallace, at Leicester, where a population of 120,000 yields 7,000,000 gallons of sewage per diem, from 20 to 30 cwt. of lime are used for every million gallons of the sewage. The sludge, containing about 30% of water, amounts to some 12,000 tons per annum. One plan for disposing of the sludge, that was tried long ago, was to convert the wet mud into a coherent paste by whirling it in a centrifugal machine, to mould the paste into bricks, and to dry them in the air. Such "Leicester bricks" contained, when air-dried, from 1½ to 2 or 3% of phosphate of lime, from ½ to 1% of nitrogen, and perhaps ¼ of 1% of potash. Considered as a manure, they were manifestly not worth the cost of much transportation. Practically, it was from the first a very difficult matter to induce farmers to use these bricks, even in places where no overwhelming quantities of the mud were produced, while for large cities the disposal of the sludge was a mere bill of expense.

One ingenious scheme, invented in England, by General Scott, was to add clay as well as lime to the sewage, in order to precipitate the impurities and to convert the sludge into cement by burning it.

It was argued, in view of the large amount of organic matter in the sludge, that comparatively little coal would be required for the final act of burning, though of course the moisture in the muddy precipitate has got to be dried out somehow. Cement of very tolerable quality has actually been prepared in this way, and it was thought that the making of it might possibly be a cheap method of getting rid of the sludge in some localities, though no actual money profit could be gained. After trial, the process has been abandoned.

Possibly a good way of getting rid of the sludge would be to burn it, together with the swill of the city, in furnaces specially adapted for the combustion of wet fuel. Such furnaces have long been in use for burning bagasse, wet peat, spent tan bark, and spent dyewoods; though perhaps in the case of the sludge some refuse coke or coal might have to be mixed with it to insure its ready combustion. (See American Journal of Science, 1860, xxx. 243.)

Yet another device, more recent than the plan of making cement, is to precipitate the sewage by means of lime and copperas, to press the sludge into blocks as if it were clay, to carry these blocks to sea, and discharge them there into deep water, out of the way of doing any harm.

As with the other processes of precipitation, the disposal of the lime sludge is really the most serious practical difficulty that has been encountered in working, and the remark is specially true of large cities, where the quantity of sludge produced is enormous. English farmers will not buy it when dry, at a price equal to the cost of drying, nor will they take it as a gift when wet, except in insignificant quantities. In many localities it has been used for filling up waste places. Wallace computed, in 1881, that the sewage of Glasgow, then amounting to from 40 to 70 million gallons daily, would produce every day 135 tons of dried sludge. In the moist state this sludge would amount to five times these figures, or 675 tons, an enormous quantity of material to be disposed of daily. If lime alone were used as the precipitant, 40 tons of it would have to be used daily. He urges that no town or city should adopt a system of precipitation until it is clearly seen how the sludge is to be disposed of.

One objection to running sewage clarified by liming directly into brooks is that the free lime which it contains is hurtful to fish. Filtration through earth does away with this trouble, or even filtration through coke slack, whereby the lime is retained or neutralized through absorption of carbonic acid from the air.

Precipitation with Magnesia.

The old idea that ammonia and phosphoric acid might be economically saved from urine was disproved long ago, as has been set forth under the head of Night-Soil; but the use of magnesia in conjunction with lime, as suggested by Suvern, has found frequent application in Germany for purifying small quantities of sewage and factory wastes. Suvern made a mixture of 70 parts of crystallized chloride of magnesium, 100 parts of quicklime, and 7 or 8 (one account says 18) parts of coal-tar, heated together; and he finally added enough water to make a thin paste containing some 9 or 10% of solid matter. By virtue of chemical reactions in the mixture there were formed hydrate of magnesia and chloride of calcium. But beside these substances there was the tar and an excess of hydrate of lime, and it will be noticed that the presence of this lime brings the process into relations with the "liming" process above described.

Suvern's thin paste was made to flow continuously in a fine stream into the current of sewage, so that it should mix therewith. The moment it came in contact with the sewage a voluminous light precipitate of phosphate of ammonia and magnesia, as well as of lime and organic matter, was formed, which carried down with it all the suspended matters of the sewage.

The mixture of liquid and precipitate was made to flow into appropriate tanks, where the precipitate settled out quickly, and so completely that the water flowed off clear and pure enough to be turned into rivers, though not into brooks. The liquid still contains much organic matter, and undergoes fermentation in the course of a few days. As much as 1.5 parts of solid matter have been found in 1,000 parts of it. It has been stated that about one third of the nitrogen in fresh sewage can be precipitated in this way, and nearly the whole of the phosphoric acid. As for the rest of the nitrogen, one third of the original quantity escaped in the form of ammonia gas, and the other third remained dissolved in the water, in the form of urea in this particular case.

Samples of dried mud from Suvern's process have been found to contain 1½% of phosphoric acid, ¾% of nitrogen, and 20% of organic matter (including tar). But in field practice the mud has been found to be practically worthless as a manure, possibly because of the tar which adheres to it. Experiments made upon farms near Berlin showed that the Suvern precipitate was not worth the cost of transportation, even at a distance of only a few miles.

Alumina as a Precipitant.

Travellers have long been accustomed to use alum for clarifying the water of bogs and foul pools to fit it for culinary purposes. The alumina in the alum, or rather a basic sulphate of alumina, combines with organic matter to form a bulky gelatinous precipitate, which drags down with it impurities that were suspended in the water. So too alum, or, better, a cheap sulphate of alumina containing some ferrous sulphate, has often been used to clarify sewage. Sometimes the action of the sulphate is made specially effective by adding, at the same time with it, enough lime to neutralize its acid, and so set free the whole of the alumina, though when the sewage contains enough free ammonia to decompose the sulphate of ammonia no lime is needed for this purpose.

Practically, it is found that a very small proportion of the sulphate is competent to precipitate the visible impurities out of a comparatively large quantity of sewage, quickly and wellnigh completely, and at the same time to deodorize the sewage. Since the whole of the phosphoric acid in the sewage, and a little of the ammonia, besides a good deal of organic matter, are carried down with the alumina, hopes were entertained at one time that the precipitate might have some value as a fertilizer, and experiments made at Paris with very large dressings of it seemed to support this view. But the analyses of Voelcker show that it must be wellnigh worthless, and the same conclusion was reached by means of field experiments upon farms near Berlin. Like street sweepings, earth-closet refuse, and many other things, the precipitate would be worth strewing upon farm land if it could be brought there without expense. But it is so nearly valueless that it cannot bear the cost of transportation.

It is said that the alumina precipitate settles rather more quickly than that produced by lime; that less sludge is formed by the alumina; and that the liquid clarified by alumina requires less filtration through earth than that clarified by lime. On the other hand, the alumina salt is rather more costly than the lime, and is hardly any more effective. The liquid clarified by alumina is equally putrescible with that clarified by lime, so that, generally speaking, the advantages of the alumina process are but slight, and it is not to be preferred to lime.

Alumina after Lime.

Mr. Peter Spence, of Manchester, has proposed to use sulphate of alumina after lime, i. e. to add the alumina salt to sewage which has already been clarified by liming it. Hereby a new quantity of organic matters are thrown down, while the free lime in the liquid is neutralized. Sewage thus doubly clarified might perhaps be thrown into small rivers without need of any earth filtration. Spence suggests that by adding dilute sulphuric acid to the alumina sludge obtained in this case, the sulphate of alumina might be revivified, and so be used over and over again, while organic matters would be obtained incidentally that would be fit to be sold as a fertilizer.

Phosphate of Alumina and Magnesia.

A process proposed by Forbes and Price in England is somewhat akin to that of Suvern. The idea was to add to the sewage a mixture of a magnesium salt and phosphate of alumina dissolved in sulphuric or muriatic acid, together with enough milk of lime to neutralize the acid by which the phosphate was held dissolved. The organic matter of the sewage goes down with the phosphate of alumina, and the ammonia with the phosphate of magnesia, and the suspended matters are enveloped in the precipitate as before.

The operation is said to be very simple, no apparatus being required, except a reservoir or tank to hold the sewage while the chemicals are added to it. The precipitation, moreover, is so complete, that the water which flows away is transparent and colorless, and to all appearance pure. Native phosphate of alumina, such as is found in considerable quantities in the West Indies, was employed, and the sludge was to be used as a phosphatic fertilizer.

The A B C Process.

This process depended upon the use of alumina (in the form of the impure sulphate, or of alum), blood, and clay and charcoal. The purpose of the blood, as in sugar refining, is that, by the coagulation of its albumen, special coherence may be given to the precipitated matters. As with the other processes of precipitation, so with this one the suspended matters of the sewage were well removed; but so much of the organic matter remained in solution that the clarified liquid soon putrefied on standing. The sewage was no better cleansed, in fact, than it was by the process of liming. Unpleasant odors arose during the drying of the sludge, though when dry it was free from smell. It has a somewhat higher agricultural value than the lime sludge, though it was found impracticable to sell, or even to give away, any large quantities of it.

The Chloride of Iron Process

has been found to be highly efficient for clarifying sewage, though it is too costly to be used on a large scale. Impure ferric chloride is used, much in the same way that sulphate of alumina is, as explained above. A heavy precipitate of ferric hydrate is formed, which carries down mechanically the suspended matters. Sulphuretted hydrogen is arrested also as ferrous sulphide, and phosphoric acid goes down as ferric phosphate. Since it is so highly charged with iron oxide, the sludge can hardly have much value as manure.

Sewage clarified by the iron process, or by the use of other metallic salts, such as chloride of zinc or chloride of manganese, may ferment in warm weather in the course of a week or ten days; but it does not putrefy so readily as that clarified by the processes previously described.

During an epidemic of cholera, in 1884, Doesburg, at Rotterdam, set up an establishment for purifying the water of the river Maas, on the large scale, by means of ferric chloride, in order to make it more fit for domestic use. The sludge obtained in this case contained 33% of organic matter and 1¼% of nitrogen. Heaps of it soon passed into a condition of violent and offensive putrefaction.

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CHAPTER XVI.

THE DISPOSING OF FARMS.

It is of the nature of a self-evident proposition, that the modes of arranging and managing different farms, even under one and the same climate, must differ widely, according to varying local circumstances. One set of conditions will lead to sheep-farming, another to cattle-grazing, another to dairy-farming, another to the production of grain, or hay, or cotton, or tobacco, or sugar, or some other special crop, while other conditions still will lead to the establishment of farms of mixed cultivation.

Since many of the conditions that go to determine the character of a farm may fairly enough be classed as chemical, it is always interesting to consider any given farm from the chemical point of view, and to try to pick out the facts concerning it which specially belong to this category.

Naturally enough, it is no easy matter to do this. The subject is complex and intricate at the best, and it is commonly difficult to separate the chemical items from a multitude of others, — social, political, and mechanical, — which are of equal or even of greater importance than the chemical considerations, but which tend to interfere with and obscure them. It is true, however, that glimpses can be got which are often highly instructive.

The significance of peat, of clay-burning, of fallows, of manure from cities, of rockweed and kelp upon a seaside farm, and of water upon irrigated land, is plain to common observation. Many analogous illustrations will readily suggest themselves. Hence an incentive to discuss in a general way some of the circumstances upon which different classes of farms depend, and to point out the dispositions of some individual farms which illustrate or enforce chemical principles.

Enduring Fertility of Bottom Lands.

Upon the highly nitrogenized, fertile, moist soil of certain river valleys at the West, where corn has been grown year after year for a century without interruption and without manure, it is certain that the farmer will have no very strong incentive to vary his crop or his modes of cultivation, provided a market for the grain is readily accessible. But if land like this is far from a market for grain, indirect methods of converting the grain to money will be resorted to. The system of farming will be changed in so far that the corn shall be fed to swine, and so converted into pork, or it will be fermented and distilled into the form of whiskey. By these devices the original crop is simply concentrated, as it were, and made compact, so that it can be carried with profit to a distant market.

Beside distance from a market, there are other considerations that might make the systems based upon whiskey-distilling or pork-feeding preferable to that of mere grain-growing. Suppose, for example, that the fertility of the land, though very great, is not inexhaustible, why then either the making of whiskey or of pork would enable the farmer to obtain manure wherewith to keep up the quality of his land, or even to enhance the value of it. One common way at the Western farms of checking the tendency to exhaustion is to harvest only the finest ears of corn, and to turn a drove of hogs into the corn-field to utilize what is left.

Land so excessively fertile as that of some of the river-bottoms in the Western country is not peculiar to America. The Nile valley offers a striking instance of the same kind of land. The fertility of the soil upon the banks of that river is so great that manures are but little employed there. Travellers often refer in terms of astonishment to the enormous heaps of refuse which accumulate in the vicinity of the Egyptian towns; and, as is well known, the saltpetre earths of Egypt are from similar mounds of refuse left by former generations of men.

So too in Palestine. The fertility of the valleys, where irrigation is possible, is very great. Dr. Hooker has said that he would engage to supply the whole population of Syria with food from the produce of ten well-cultivated miles of the valley of the Jordan.

Farms in Sterile Hilly Districts.

In contrast with these fertile river-bottoms may be cited a country of steep and rocky hills. Here the only alternative is pasture or woodland. But there are a great variety of dispositions possible nevertheless. Some of the small New Hampshire rivers, like the Pemigewasset, which flows from the Franconia Notch into the Merrimack, and the Saco River in the Conway region, carry tolerably wide intervales in the heart of a very broken and hilly country. The prevailing disposition of farms in that region is a quantity of hill-land behind the homestead, and a strip of intervale in front. Sheep are pastured on the wild hills through the summer, and kept up in winter upon hay grown upon the intervale. A little maize and a few potatoes and oats are grown, of course, and a few cattle are kept, as well as the sheep; but the basis of the farms is sheep, in many instances. It is so hard a matter to carry on profitable husbandry in that region, excepting where the fertilizing influence of the river is felt upon the intervale, that the hill farms, properly so called, i. e. those situated wholly upon the hillsides, and devoid of intervale, are falling away every year. Their owners desert them, house and land together, and move away to some happier clime. No doubt this emigration might be checked by the introduction of rational systems of recuperating the worn-out pastures of the hill farms, and by the judicious use of composts (made from peat or sods) and of artificial fertilizers on those patches of land which are smooth enough to be mown. Rough and ready methods of drainage also, and of irrigation, might doubtless be used in some places; but it is hard to introduce innovations such as these, so long as there is richer land at the West to be had almost for the trouble of taking it.

Mr. Darwin, in his Narrative of the Voyage of the Beagle, has described a somewhat similar state of affairs as existing in Chili. Between the parallel mountain ranges of that country, there are numerous level basins, or plains, which are easily irrigated, since they slope naturally towards the sea, and there is no lack of water from the hills. Thanks to the irrigation, these plains are singularly fertile, though without irrigation the land would yield nothing, for during the whole summer the sky is cloudless. The mountains and hills are dotted over with bushes and low trees, and excepting these the vegetation is very scanty. Each land-owner in the valley possesses a certain portion of hill country, where his half-wild cattle in considerable numbers manage to find sufficient pasture. Once every year there is a grand "rodeo," when all the cattle are driven down, counted, and marked, and a certain number separated to be fattened in the irrigated fields. Wheat is extensively cultivated, and a good deal of Indian corn. A kind of bean is, however, the staple article of food for the common laborers.

Farms maintained by Forage Crops.

Between the two extremes just mentioned, viz. the inexhaustible river-bottoms of the West on the one hand, and the rocky pastures of New Hampshire on the other, may be found an almost infinite diversity of arrangements. A good example of the way in which the continual grain-growing of the West has to be modified as the quality of the land begins to depreciate, may be seen in New York and Ohio, where clover crops are now often made to alternate with wheat, as has been stated under the head of Rotations. The clover fodder is used, of course, to produce dung, not to speak of the fertilizing value of the roots and stubble which are left upon the land. At the South, the cow pea serves instead of clover, and in some instances it appears to be an excellent alternative. A rotation practised in some parts of Georgia consists of oats and cow peas, as follows. Oats sown in October are ready to cut by the middle of May. The oat stubble is ploughed under, cow peas are sown, and the vines are mown for hay in August. This hay is said to be of excellent quality. The second growth of the peas is ploughed under, and oats sown again in October or November. This rotation may be kept up for long terms of years, — "forever," as the saying is in that locality.

An analogous example of the need of interpolating forage crops such as refresh the land may be drawn from English experience. There was a time not long ago when, theoretically speaking, by far the most profitable crops that could be grown on rich clay soils, in some parts of England, would have been wheat and horse beans. The products would have been readily salable at high prices, and the two crops suit one another extremely well when grown in alternation. But in case this experiment had been tried upon an entire farm, not half enough manure could have been got from the straw and haulm to keep up the fertility of the land. Nowadays such a farm could probably be maintained readily enough by means of artificial fertilizers, though it might no longer be profitable to do so in England because of free trade in grain. But it would still be true on any farm that intended to make a specialty of the two crops in question, that it would usually be more profitable to grow hay and oats for the work-horses, and hay at least for a cow or two, than to buy these products; and on this account, if for no other reason, there would be a strong incentive to mixed cultivation.

Potato Farms.

Formerly much more than now, i. e. before the introduction of the fungus which caused the disease known as the potato rot, many farms in certain parts of New England were based on the growing of potatoes. On the coasts of New Hampshire and Maine, and of Nova Scotia also, — wherever, in short, there was access to water carriage, — the potatoes were shipped as such, to be eaten as such, while in the interior of the country starch was made from them; that is to say, they were converted into a substance which is easily transportable, and for which there is a constant and large demand all over the world. The refuse from the starch factories has a certain small value as cattle food, and a part of the crop itself was not infrequently used as fodder, and so for the production of dung, and the potato vines were left upon the land; but the main point was that a non-exhaustive merchantable crop was produced as the chief resource of the farm. Usually the potato crops were supplemented with moderate crops of forage and grain, for household use and for the support of cattle.

It is difficult for any one who was not actually upon the ground at the time to realize the terrible destruction of farms that was caused in Nova Scotia in particular by the potato disease of 1847–48. Starch and whiskey and sugar (glucose) are still made from potatoes in Germany, upon a very extensive scale, and many farms based on potatoes exist in that country.

Influence of Indian Corn on Farming Methods.

But in this country Indian corn has largely replaced the potato as a source of these products. Indeed, Indian corn, which has always been the basis of American farming, has become more than ever conspicuous since it has pretty thoroughly superseded the potato as a starch-producing crop. Corn is remarkable, not only for its easy cultivation, but for its enormous yield both of food and of fodder. It is at once a grain crop and a forage crop; or, even more emphatically, a bread crop and a fallow crop. Practically it has hitherto in good part, if not entirely, done away with the need of cultivating roots for cattle food in this country, and it has enormously curtailed the growing of leguminous forage crops also. It is a highly interesting and a still debatable question as to how and when and where (if anywhere) systems of farming based on the supplementing of Indian corn with roots may best be practised.

As long ago as 1816, the famous English political writer Cobbett proposed to base a farm on Long Island, 20 miles from New York, on rutabagas, cabbages, and Indian corn, as follows. He proposed to have a farm of 100 acres, of which 12 acres should be in rutabagas, to yield 500 bushels to the acre; 15 acres in corn, well tilled, with white turnips sown at the time of last ploughing, to yield 40 bushels shelled corn and 1 ton fodder to acre; 3 acres of early fodder cabbage, planted at various times [according to a French practice]; one acre of mangel-wurzel; one of carrots and parsnips; and 12 acres of orchard kept in grass. The rest of the farm would be devoted to hay and grain for sale.

He would keep 4 working oxen, 3 cows, and 14 breeding sows all the year round, and at least 100 ewes, would begin to feed rutabagas on the 1st of February, when they are at their best, and would sell off fat stock during the spring. By the 1st of July he would put the ewes upon cabbage, and fat them therewith, in addition to the grass of the orchard. Cabbages, fall-feed from the grass and grain fields, and corn-stalks, were to carry the stock until the 1st of December, when white turnips, mangolds, and the other roots would be fed to them. The hogs were to be finished off with a little corn.

Besides hay and grain, he calculated to sell 100 early fat lambs, 100 hogs of 240 lb. each, 100 fat ewes, 9 quarters of beef, and 3 hides, and argued that the meat products alone would bring him in $3,000, less the cost of 100 new ewes and 3 oxen. No doubt rutabagas and cabbages are fattening food, but they are uncertain crops.

Influence of Roads on Farm Arrangements.

As has been said, it is often wellnigh impossible to distinguish accurately between chemical and mechanical conditions in studying this question of farms. Thus, the mere difference between good and bad roads, or between a rough and a smooth country, will often make a very material difference as to the kinds of crops grown and of manure produced upon the farms, and so of course upon the mode of carrying on the farms. In a smooth country provided with good roads, all the heavy transportation and the farm operations will usually be performed by horses, while in a broken country oxen are almost absolutely essential for the practice of agricultural operations. But oxen can be well maintained on much rougher forage than is needed by horses, while in respect to patience and fortitude the ox is greatly superior to the horse. If a wagon is "set" in a muddy road, or if any serious obstruction impede the draught, a horse, or a team of horses, will soon lose heart. Not only is the horse apt to fret himself unduly when thus troubled, but it usually happens, after the first trial or two have failed to overcome the impediment, that he becomes disheartened and practically useless. But a steady ox will try again and again, as often as the driver may care to urge him, or until the difficulty has been overcome. Captain Marcy, in passing from Utah to New Mexico over the Rocky Mountains, in winter, set out with horses, mules, and oxen, the latter to be used as food. "I found," he says, "as soon as we struck snow three feet deep, that the mules directly became disheartened, lay down, and would not exert themselves. The horses seemed more ambitious, and would push their way through the snow as long as possible; but they soon became weary and gave out from exhaustion; while the oxen slowly and deliberately ploughed their way through the snow for a long time without becoming jaded." They also subsisted better than the other animals on the pine boughs and browse which were their only food.

Oxen too clumsy for civilized Farms.

It may here be said that the chief reason why oxen are so little used nowadays in the smoother parts of New England, as compared with their abundance at earlier periods, seems to depend on the fact that oxen cannot so well be used as horses for hauling mowing-machines, hay-rakes, cultivators, and all the modern machinery which makes farming possible in these parts. One reason why so many of the hill farms in New Hampshire have been deserted is, that the horse implements cannot so readily be used upon those farms as elsewhere; that is to say, under the modern methods of farming, the rough hill farms are put at a still greater disadvantage than they were formerly. The introduction of machines for securing the hay crop, in particular, has made it so much easier and cheaper to get hay from smooth land, that many of the rough farms can no longer compete with the smooth, even when the rough land is equally fertile with the smooth land, or even more so. Precisely the same thing is seen almost everywhere in New England on the rougher parts of smooth fields, where the mowing-machine cannot readily be driven. Many such spots are now left to be overgrown with weeds and bushes, which were formerly kept neat and clean by the scythemen; and the worst of it is, that such patches tend constantly to increase in size from one year to another, unless resolutely opposed.

According as oxen or horses are kept, the farmer will naturally grow different kinds of fodder. Even different grades of hay will be required, and on this account there will be a much stronger incentive to drain low-lying meadows on farms worked by horses. And in general the tillage, the crops, and the character of the dunghill will differ because of the different modes of feeding and working the two kinds of animals.

In contrasting the horse and the ox in this way, special reference is had to this country and to England. But it is a fact that upon many parts of the continent of Europe the small farmers use cows, almost universally, as beasts of draught, precisely where the country is flat and the roads excellent. This exception does but enforce the argument, however, as to the influence of circumstances upon the conduct of farms. If the cottager can get a beast of draught that will not only plough his field and carry his produce to market, but at the same time yield some milk, the facts of smooth roads and easy tillage will influence him only in so far that they render the stark strength of the ox unnecessary. As for the gain in time to be had by using horses, that will have little significance where the amount of hard work of any one kind to be done is small, and infrequent. It may be said, in passing, that this practice of using cows as beasts of burden seems to be a commendable one for the conditions under which it occurs.

Under still other conditions, as in some parts of Italy and of India, the wellnigh amphibious buffalo is preferred to any other animal for agricultural operations, and even as a beast of burden. These animals are particularly well adapted for ploughing rice-fields, since they can work in mud that is knee-deep. At Sudashiapet Mr. Mitford saw them working in this way, and noted that, when released, they could be seen "wallowing in the muddy pools, basking in the sun, with their backs covered with frogs."

Another instance of the influence of external conditions upon the modes of farming may be seen in the Chinese practice of using human excrement as a manure. It has been remarked by several travellers, in explanation of the general use of this substance in China, that it may depend, not upon any intrinsic worth of this kind of manure, but upon the fact that comparatively few cattle are kept in that country. Manual labor is general throughout the empire; very few animals are used for cultivating the land, or kept for any purpose; and, besides, the Chinese are a nation of cottagers or small farmers, — a class more likely than any other to save every kind of manure that may come within reach.

Changes due to Railways and Steamships.

But the most striking instance of all is the change in the character of farms pretty much over the whole world, which has been brought about by the cheapening of transportation in recent years, particularly that of grain and cattle, from the Western States of America, and of grain from India. The invention of Bessemer steel, and the building of railways with it, improvements in the building of steamships and of compound engines to drive them, as well as the construction of grain elevators, and the carrying out of improved systems of organization, have practically changed the scope, and plan, and attitude, so to say, of English farming in particular, and have undoubtedly considerably modified the farms of most other regions. These changes have given a very severe blow to "high farming," properly so called, for now transportation is so cheap that when produce has once been put into a ship or car, it costs but little more to move it 600 or 800 miles than it does to move it 100, and wild cheap lands have a preponderating advantage; for the first cost of growing grain upon them, or of rearing stock, is extremely low. As illustrating the economy of transporting large quantities of produce to great distances, the story is told of a Western city where 50 cents has to be paid for moving a barrel of flour from the mill to the door of a dwelling-house, while only 35 cents more is required to land the barrel on the dock at Liverpool.

The Size of a Farm a Matter of Executive Power.

The sizes of farms, and sometimes their characters as well, are commonly determined in good part by the degree of superintendence required. Mere pasture farms are the largest. Next in size, as a general rule, are those composed of mixed pasture and tillage; then come arable farms, and so, through all conceivable degrees of diminution, down to the smallest garden.

High and Low Farming.

As is well known, there are two great classes of farms; viz. those based upon "*intensive*" culture, — "high farming," as the English call it, — and those based upon "*extensive*" culture. In the first class, large crops are produced at the expense of much labor and capital; and in the second class, small crops are obtained at very small cost.

The distinction between the two kinds of farming has been mentioned already; but the subject is one that invites discussion, and much might be said upon it. The student will do well, at the start, to dismiss from his mind any conceptions which may have entered it, either to the effect that high farming is necessarily good farming, and to be striven for, or that extensive farming is necessarily bad farming. For neither of these opinions is tenable.

High farming may be good in one place and very bad in another, and the same remark is true of low farming. Everything depends upon the situation of the farm with regard to the rest of the world. There are very few places indeed, if there be any, of which it can be said with truth that good farming consists in getting the largest possible yield from a given piece of land.

What is Good Farming?

The true definition of good farming, and it is one that will apply everywhere, is that it consists in getting the highest possible profit from the land, year in, year out. As a general rule, the true aim of the farmer is not to bring his land up to a high pitch of productiveness, but to make the best possible use of the ways and means at his disposal. Formerly, in case manure was costly and labor cheap, it may sometimes have been well to till the land carefully. But when labor is costly as well as manure, it will often be the best policy to do away with labor, in so far as may be possible, and to throw one's self upon the natural forces of the land.

Manifestly, the definition of good farming above given will include even that kind of practice in which the soil yields only a minimum crop, provided the cost of growing, collecting, and marketing that crop is sufficiently small.

Examples of Low Farming.

Practically, there can be no shadow of doubt that systems of extensive farming are often the best possible systems for the conditions under which they are practised. The farming customs of many uncivilized tribes well illustrate this point. For example, Mr. Hunter, in his description of the Indian province Orissa, says: "The Governor told me that, as he is anxious to extend cultivation, he asks no rent from any jungle tribe that will settle down. They may cut down as much forest as they choose, and cultivate the clearing as long as they please. But all his efforts have failed to induce the nomadic tribes to submit to the toil of permanent husbandry. They willingly burn a patch of jungle, but avoid the chance of any question of rent arising by deserting their clearing every third year. This practice simply means, that, where land is to be had for the clearing, it pays better to take a rapid succession of exhausting crops off the virgin soil, than to adopt the laborious processes of regular cultivation. The forest tribes show great talent in making a livelihood with the minimum of labor, and this is one of the ways in which they solve the problem."

Another, and evidently a better account of the matter is given in Captain Forbes's "Travels in Burma": "The great peculiarity of all the 'hill tribes' of India is their unsettled and ever-changing mode of life. They are all 'nomadic cultivators.' To raise their scanty crops, the virgin forests on the steep slopes of the hills must be cleared and burnt; but the excessive rainfall soon washes the friable soil off the surface, so that only one or two crops can be raised on the same spot until it has again been allowed to become overgrown with jungle, and a fresh deposit of earth has formed. This system of agriculture naturally requires a large extent of country. It is not every hillside that is favorable for cultivation; consequently in two or three years all the culturable patches near a large village become exhausted, and the whole community must move off to new localities, perhaps thirty or forty miles away, since they may not trespass on what is regarded as the range of another village. Hard and bitter, indeed, is the struggle for life of these hill men. Every year the dense forest must be attacked, and with infinite labor large trees, six feet in girth and 100 to 150 feet or more in height, have to be felled, cut up, and burnt, to clear the ground. And then fences have to be made to keep out wild hogs, deer, and elephants." In Burma the usual crops are hill rice, maize, roots, and greens, with enough cotton for domestic use.

Another instance of extreme extension is seen in the old Spanish ranches of California and Texas, where great droves of cattle were herded from place to place, according to the state of the grass. At one time the only merchantable products of these ranches were hides, horns, and tallow.

The sheep farms of Australia and New Zealand exhibit the same things; much land, little labor, and no very great amount of capital being devoted to the production of wool, skins, and tallow.

Many of the moorlands and heaths of Europe are in pretty much the same category, and so are those brush farms of New England, where the land is burned over once in a good many years, and a crop or two grown upon the ashes. Wherever land is cropped for a year or two, or for any small number of years, and then left fallow, the agriculture is of course extensive, and this state of things will usually be found wherever land is cheap and labor costly, where the means of transportation are limited and money scarce.

Mr. Seebohm, writing at Ust-Zylma in Siberia, a town some hundreds of miles east by north from Archangel, says the cattle are fed principally upon hay, which is cut upon low lands on the river's bank. These lands are flooded every spring, and any manure placed upon them in winter would speedily be washed off; nor is it needed, as the river itself is the great fertilizer in these low-lying districts, just as the Nile is in Egypt. The winter is long, and the length of time during which the cattle are stall fed so great, and the amount of upland available for cultivation so small, that there is always a large surplus of manure, which the peasants do not think worth the cost of preservation. So much manure is allowed to accumulate in the streets that the town is one vast dung-hill, until the refuse is washed away at the time of the spring thaw, when the river overflows its banks.

Many of our Western wheat-fields afford admirable examples of extensive farming. The value of the crops obtained from each acre of the land often seems absurdly small, and over wide areas the crops may not be equal in amount, on the average, to as much as one third of what is usually harvested in Great Britain; and yet the Western land is so cheap, and the cost of growing grain upon it is so small, as well as the cost of transporting the grain, as has been said, that the farmer still finds so wide a margin of profit that he has practically overcome those rivals who try to grow grain intensively.

It does not necessarily follow that poor land will always be cultivated extensively, though it is usually. The sand dunes of Spain and Holland, mentioned on pages 58 and 59 of Vol. I., are exceptions to the rule, and so are some farms in the Belgian Campine, when irrigated and fertilized, as described on page 178 of Vol. I.

Grass Farming usually Low Farming.

Almost all systems of farming which depend upon the production of hay or grass are extensive, though some of the modern systems, in which grass forms one step in an otherwise intensive rotation, should be excepted; as well as some of the systems based upon the feeding of cattle with cut green fodder exclusively.

In all wild or new countries, extensive farming is in some sort a necessity of the case. For land is worth so little in those regions that it is cheaper to use a great deal of it to produce a given effect, than it would be to obtain this effect upon less land by means of dung and tillage. It is rational and advisable in such cases to rely more upon the natural forces which are close at hand, than upon human appliances, such as labor and capital.

Low Farming requires much Land.

There are, of course, all shades and degrees of farms between those which are purely extensive and those which are really gardens, so intensively are they cultivated. But as regards extensive farming it is easy to conceive of conditions under which it will be best to keep the element of labor, whether of man or beast, as low as may be practicable; to avoid as far as possible all crops that require much cultivation; to send the cattle into the field in the early spring, and to keep them out as late in the autumn as may be consistent with their welfare; — and to this end a large farm, i. e. a great deal of land, is essential.

There is less sense than would appear at first sight in much of the talk against large farms that fills our New England newspapers. Where due attention is paid to the conditions which control the disposition and conduct of a farm, the size of it is a matter to be regulated solely by the administrative power and business faculty of the person who works it, and the amount of capital at his disposal.

A noted French writer upon agriculture, Moll, has argued that the chief error in the agriculture of his own country even is the employment of too much labor; more, he says, than the mediocre fertility of the land will justify. It is to this cause, among others, that he attributes the decline of large farms in France; the comparatively costly hired labor of the great farms cannot compete with the family labor of peasant proprietors.

Localities fit for High Farming.

It is on rich soils, and upon tolerably good soils near a quick market, i. e. either in the vicinity of densely populated places, or where from a favorable climate, or some other peculiar circumstance, some special crop can be made to prosper, that intensive farming finds its place. In the Champagne wine region, in our own cotton and tobacco districts, and upon the Cuban sugar plantations, high farming pays, though it is not always practised. It is seen at its best in England, Scotland, Belgium, and Saxony, where good land, abundant capital, and dense populations are coincident. It would be palpably absurd to practise the Flemish garden husbandry in a sparsely settled country, far from any great centre of population.

European writers tell of farms in some parts of France, and in the mountainous regions of Germany, where the labor of 3 men and 2 horses is sufficient for 250 acres of land, while in the market gardens around Paris the labor of 700 men and 120 horses is expended on that amount of land. But in both instances the farming is excellent.

Mr. Caird holds that the maximum of fertility for England, taking land in its natural state, is a rich pasture capable of fattening an ox and two sheep on an acre. Such soils are exceptional, though met with in most counties. He cites the Pawlet Hams in Somersetshire, which is a tract of rich alluvial soil on the river Parrott, stretching along the seaboard. It is in permanent pasture, and lets for $25 or $30 the acre for grazing. Some of the marsh lands of Sussex and Kent are of equal value. The minimum of fertility he exemplifies by a bleak mountain pasture, where ten acres will barely maintain one small sheep. He adds that the artificial maximum and minimum of fertility which result from the treatment of soils of the same quality may be illustrated by taking two of the experiments of Mr. Lawes. The average of the last twelve years out of thirty gives the following results: —

	Grain. lb.	Straw. lb.	Total. lb.
Wheat, average of last 12 years, no manure . . .	730	1,120	1,850
" " " " with special manure	2,342	4,928	7,270

The soils were similar, strong land on clay, with chalk below; the management was the same, and all the other circumstances. The only difference was that there was no manure for thirty years in the one case, and an abundance of manure in the other. Three times as much grain, and four times as much straw, were got by the expenditure of an amount of manure which gave a profit of 100 per cent.

Few Farms are purely Extensive.

In reality comparatively few farms can be found every acre of which is cultivated intensively, and there are hardly any farms that are wholly destitute of patches of garden ground, devoted to what, for the sake of contrast, may be called high farming. The true rule in every case is that that style of farming should predominate which yields permanently the largest profit. It is quite right withal that there should be a marked contrast between the main body of a farm cultivated extensively, and the garden patches upon it. All the manure which is to be had upon such a farm should be devoted to the dressing of a comparatively small area of the best land. It is usually better in such cases to manure 10 acres of land thoroughly, than 20 acres insufficiently; for by the former plan only about half the labor that would be required by the latter will be expended.

This is the argument to apply to our New England conditions. Instead of joining in the common cry in favor of smaller farms, it will be well to urge careful cultivation of the best portions of the existing farms, and an extensive treatment of the remainder. Much good might be done, no doubt, at small cost, by taking pains to improve bog meadows, and those old pastures which are capable of improvement, and by favoring the growth of wood upon those portions of the land which are worthless for other crops; but, speaking in general terms, it is not likely that the character of the agriculture of this section will undergo any very material changes for a long time to come.

It is not easy at any time to change the husbandry of a section of country, or of a farm, all at once, from extensive to intensive. Excepting the cases where land may be drained or irrigated, much time and patience are required to bring up poor land to a medium state of fertility, even when the physical conditions are favorable. But that even the poorest land can after a while be made fertile is well shown in the gardens about dwelling-houses. It has been often remarked of European farms, that, if one were to judge of the land of a district by the luxuriant vegetation around the farm-houses, he would usually be grossly deceived. The gardens are constantly receiving fertilizing materials, both intentionally and without forethought. The refuse that falls from a house, in the course of generations, is of itself sufficient to fertilize an appreciable patch of desert, provided only that the land can be kept fairly moist, and that poultry are kept away from it.

Moisture essential to Fertility.

It would be idle, however, without control of water, to expect heavy crops from poor land, or to apply forcing manures to such land in the hope of great profit. No land can be made to pass for more than it is worth, or to do better than it can. For each and every kind of land there is some one best possible rate of applying manure, and the rate for poor land is very different from that for rich land. It is precisely this consideration that naturally leads the farmer to devote his energies to the best lands upon his estate, and to let the poorest lands remain as wood or pasture. The argument in favor of intensive culture upon a small portion of an "extensive" farm is a mere continuation of the same general idea.

The Character of a Farm not to be changed all at once.

The true way of changing from "extensive" to "intensive" culture would be gradually to enlarge the amount of land upon the farm that is cultivated intensively, i. e. as fast as the thing could be done profitably. There is one reason why this change should not be made rapidly upon any single farm which is often lost sight of by amateur farmers, and that is the fact that it is rarely worth while (from the commercial point of view) to make a single farm very much better than the farms that surround it. The price of every farm, no matter how good the farm may be, is largely dependent upon the price of the neighboring farms. No rapid improvements in the quality of a farm can be made except at considerable cost. But the capital expended could hardly be recovered on selling the farm, unless the neighboring farmers had at the same time improved the character of their possessions.

The more intelligent and appreciative the man might be who proposed to buy the improved farm and settle in this supposed neighborhood, so much the more likely would he be to argue "what man has done, man can do." He would probably rather buy one of the poor farms and seek to improve it, than to purchase the property which had been already improved.

It is not to be understood that the argument is directed against the improvement. It is urged only that changes must be gradual to be healthy, and that no one man can all at once alter the habits and customs, and the standard of value, of his neighborhood.

Contrast between Cost of Crops from Good Land and Poor.

The following computation as to the comparative cost of growing wheat when feebly or fully manured, is taken from the French of Malaguti and Lecouteux. It may serve to illustrate the proposition that labor may usually be expended to much better advantage upon good land than upon poor land, and that, as a mere extension of the same idea, it is more profitable to manure a small field generously than a large one insufficiently.

Starting with a five-acre field, the idea is to manure the land in such a way that the wheat crop (when its turn comes in the rotation) shall absorb 26,400 lb. of manure from one half the field, and 44,000 lb. from the other half. It is admitted that every 10 lb. of manure absorbed stand for a yield of 1 lb. of wheat, so that the manure upon the lightly manured half of the field will give a crop of 2,640 lb., or say 42 bushels, of wheat; while that upon the half which was more heavily manured will give a yield of 4,400 lb., or over 70 bushels, of wheat.

Admitting, furthermore, for the sake of the argument, that the manure costs a little more than 7¼ cents the 100 lb., the 2,640 lb. of wheat (due to the 26,400 lb. of manure) will have cost $19.20 on account of manure, and in the same sense the 4,400 lb. of wheat (due to the 44,000 lb. of manure) will have cost $32.

But the cost of a crop does not depend alone upon that of the manure. There are a number of other items to be taken into the account, such as labor, seed, ground-rent, and interest on the capital employed; and the sum of these expenses added to the cost of the manure will raise to $1.40 the cost of each bushel of wheat harvested on the lightly manured half of the field, while the cost of each bushel of grain harvested on the richly manured land will be $1.25.

Reckoning the straw as worth $3.60 a ton, and that there are 132 lb. of it for each bushel of wheat, the cost of the bushel of grain will be reduced to $1.16 and to $1.00 in the two cases.

Finally, if the wheat is sold at $1.20 the bushel, and the straw at $3.60 the ton, the profit on that half of the field which was lightly manured will be $1.80, and the profit from the half of the field which was well manured will be $16.40.

A prominent farmer in the district of Brie, in France, who is said to practise high farming in a skilful way, has recently stated that he could afford to sell wheat at $1.13 the bushel when the yield is 40 bushels to the acre; at $1.33, when it is 34 bushels; and at $1.60, when it is 28 bushels.

Manifestly, there might be a decided advantage in cultivating this crop intensively on that farm were it not for the competition of American wheat, which was said to cost at the time about $1.12 the bushel when landed in France.

So, too, with Indian corn. As long ago as 1841, Mr. Colman, in his 4th Report on the Agriculture of Massachusetts, page 20, gave estimates of the cost of cultivating an acre of corn in the Connecticut Valley, one of which was essentially as follows:—

Preparatory ploughing and harrowing	$5.00
Five cords of farmyard manure	12.00
Carting the manure and putting it in the hills	4.00
Seed and planting	1.75
Cultivating and hoeing	5.00
Gathering and husking	5.50
Interest on land and taxes	6.00
	$39.25
The crop was 40 bushels of shelled corn,—and stalks (stover) estimated to be equal in value to 1 ton of hay [1]	10.00
Actual cost of 40 bushels of corn	$29.25
Actual cost of 1 bushel of corn	0.73

Mr. Colman remarks, that "the judgment of some of the most intelligent farmers of this vicinity places the average yield of corn at 35 bushels to the acre."

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[1] According to the usual allowance, that 100 lb. of stover are harvested for each bushel of shelled corn, there would have been 2 tons of stalks in this case, worth, according to the present manner of estimating, some $16 to $20, which would reduce the cost of the corn to the neighborhood of 50 cents the bushel.

In contrast with the foregoing may be cited a crop of corn grown on 9½ acres of land, by Mr. E. F. Bowditch of Framingham, in 1875.[1] The round figures given in the table, as obtained by reducing to one acre Mr. Bowditch's estimate of the entire crop, are not literally correct, since they indicate that his crop cost rather more than was actually the case. They are given here merely for the sake of comparison.

Preparatory ploughing and harrowing	$5.00
Fertilizers, viz. 462 lb. of sulphate of ammonia, 177 lb. of muriate of potash, and 163 lb. of bone-black treated with 81 lb. of sulphuric acid	33.00
Mixing, carting, and spreading fertilizers	1.40
Seed and planting	1.60
Cultivating and hoeing	5.00
Cutting and stooking	3.00
Husking	11.50
Stowing the stover	7.50
Interest on land and taxes	5.50
	$73.50
The crop was 115½ bushels of shelled corn, — and 5¾ tons of stover, which was reckoned to be worth at $8 the ton	46.00
Actual cost of the 115½ bushels of corn	$27.50
Actual cost of 1 bushel of corn	0.24[2]

This large crop was grown upon grass sod which had had no manure for three years, and which had been ploughed under, seven inches deep, in the autumn of 1874. The soil was a dark-colored loam, upon a sandy clay subsoil. One half of the mixture of fertilizers was spread broadcast in the spring of 1875, and the other half strewn in the drills and covered with the foot before the seed-corn was dropped by hand. The forcing effect of the large dressing of sulphate of ammonia is manifest.

In respect to root crops, the contrast between proper and improper manuring can be shown even more emphatically, perhaps, than with grain crops, for it is manifest that the labor expended in cultivating and harvesting large roots must be proportionally small. Five tons of turnips waiting to be lifted from one acre of land will commend themselves more than a considerably larger quantity scattered over three acres. Of the two crops of potatoes contrasted in the following table, the smaller is copied, with modifications, from one of Mr. Colman's examples of the cost of growing this crop in Middlesex County, Mass., and the larger is a crop grown by Mr. David Whiton of Hingham, in 1874. The figures all relate to one acre of land.

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[1] Abstract of Returns of Massachusetts Agricultural Societies, 1875, p. 140.

[2] Mr. Bowditch's more precisefigures give 22.4 cents as the cost of one bushel of the corn.

OUTLAY.

	Colman.	Whiton.
Preparatory ploughing and harrowing	$6.50	$8.00
Manure	16.00[1]	71.00[2]
Seed and planting	7.30	30.50
Cultivating and hoeing	5.00	18.00
Digging, &c.	5.00	30.00

INCOME.

In Colman's case, 150 bushels of potatoes were harvested, worth say 50 cents the bushel . . .	$75.00	
In Mr. Whiton's case, 461½ bushels were obtained, the potatoes being "very smooth and very even throughout the piece"		$230.50

As a matter of course, such reasoning as the foregoing can only apply to fairly good land. As everybody knows, there is a limit beyond which no profit can be gained by manuring more heavily. Mr. Lawes has stated the matter very well in the following terms: "Many of the charges connected with farming are much the same, whatever may be the value of the crops grown. Of course it costs something more to harvest a large crop of grain than a small crop, and the expenses on a heavy crop of roots will be somewhat greater than on a light one. Still, it may be said with truth, that, with the exception of the money paid for manure to grow the larger crops, the charges remain very much the same, no matter whether the amount and value of the produce is large or small. Hence, if the increase of produce did but stand in a constant proportion to the amount of manure applied, that is to say, if the application of two or three times as much manure would but double or treble the crop, then high and ever higher farming would be a remedy for low prices."

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[1] Eighteen loads of barnyard manure, of which twelve loads were spread, and six loads were put in the hills.

[2] Mr. Whiton's potatoes were grown upon dark-colored gravelly loam, which was in grass, without manure, in 1872, and in 1873 also until August 1, when it was ploughed 10 inches deep and dressed with 420 bushels of manure from a barn cellar for millet, which yielded two tons of hay. In April, 1874, four tons of rockweed were ploughed in 7 inches deep. After harrowing the land, furrows were drawn, and 600 bushels of barn-cellar manure were spread in them. After planting the seed potatoes, a small handful of phosphate (600 lb. in all) was scattered over each set. It will be noticed that the land was left highly charged with manure for the use of succeeding crops.

There is no need to insist how narrow the scope of this reasoning is. The moment a certain limit is passed, the cost of the manure required to bring a given amount of gain increases much more rapidly than the proportion of the fixed expenses diminishes.

Farming of Pioneers.

It often happens, when a country is first settled, that the inhabitants gain money by lumbering, or fishing, or even by hunting, and that the farms are made to depend almost entirely upon the natural forces of the soil, i. e. crops are grown without manure, and cattle are maintained upon wild pastures and upon the hay of bog meadows, prairies, or salt marshes. If the country is broken and hilly, or if its soil is poor, pasturing or lumbering in one form or another may forever continue to be the prevailing occupations, as is seen to-day in the Tyrol, in Switzerland, Norway, Sweden, Canada, Maine, and New Hampshire.

It may be said of this primitive husbandry, that, if uncontrolled fires could be prevented, land devoted solely to wood and to pasturage, and so protected from being washed away by rains, would not deteriorate so rapidly as is the case in some of the better defined systems of extensive farming. Trees, in particular, obtain their food at comparatively great depths and from wide distances, and are consequently less apt to exhaust the soil than crops which act more superficially. It is well to consider what large amounts of produce are obtained from the land by fruit trees in various parts of the world, — i. e. by apples, pears, plums, peaches, apricots, olives, chestnuts, oranges, lemons, walnuts, dates, etc., — and to reflect how small a proportion of manure is expended upon these crops. It is only with the advent of methods of farming which leave much land bare, or where crops are continually carried off from the land without any compensation, that the soil need begin to suffer much.

It is noticeable that, generally speaking, the gross product of woodland is less than is obtained when the same land is devoted to agricultural crops. According to Boussingault, a forest in the Vosges produces annually some 3,000 lb. of dry wood to the acre; while, taking one year with another, the same soil would yield of dry products to the acre, if it were devoted to

Wheat (and straw)	3,500 lb.
Hay	3,900 "
Clover or lucern	4,500 "

Excepting very fertile prairie countries, it has not usually happened that any very abrupt or sudden transition from the condition of woodland or of pasture to that of arable land has occurred. On the contrary, the two systems of husbandry ordinarily shade into one another by insensible degrees. The earlier settlers till a portion of the pasture or the woodland for a few years, until it begins to run out, and then they leave the land to itself for a term of years, during which it reverts to grass or to wood, as the case may be. This system in its turn gradually changes to one of rotations, in which bare fallows are numerous, and these fallows, in European experience, have come to be fertilized in due course; at first by folded sheep, and then by farmyard manure.

Good Land depreciates but slowly by Cropping.

The experiments of Lawes and Gilbert have taught a highly instructive lesson as to the slow rate of exhaustion of really good land when it is cropped continually without being manured. For more than forty years they have grown grain crops incessantly without manure, upon what was originally good wheat-land, and during all this period the crops have fallen off at the rate of from ¼ to ⅓ of a bushel to the acre each year. This decline they attribute almost wholly to the gradual using-up of the nitrogen that was originally stored in the soil. It will be noted that although a third of a bushel of grain to the acre may seem no great matter when only a single year is looked at, this annual decline will amount to ten bushels to the acre at the end of thirty years, which is a quantity well worth manuring for.

Causes of "Improved" Farming.

Although, theoretically speaking, it might be possible to keep land in good heart by either of the methods of farming above cited, provided only the land were left at rest during sufficiently long periods, and were protected from fire, and from washing by rain, it is none the less true that in reality men are not thus care-taking. They squeeze from the land what they can get, and they are quite right in doing so, provided they do not press too hard. They seek always the highest profit from the land, and when, through increase of population, the time comes for getting profit by treating land more generously, it happens that what are commonly called improved methods of husbandry will be slowly established. The reason, by the way, why the more recent methods are called "improved" is, that fit alterations and adaptations of old methods to meet changed circumstances and new requirements are never generally adopted into a district so rapidly as they might be. There is always need of much debate, as well as criticism and condemnation of the older processes. Usually, many years must pass by before a prevailing system of husbandry can anywhere be changed; and, for that matter, perhaps, there is no place in the world where the system in vogue is everything it should be. It has been well said, that men may be improving old methods perpetually, and yet the amount of good in the world remain much the same.

Practically the earlier methods of farming do tend slowly to depreciate the soil. It is only when methods are adopted which are based upon green fallows and stock keeping, or on irrigation, or the use of artificial fertilizers, that the fertility of land is fully kept up.

This point is well illustrated by a letter from Jefferson to Washington, written in 1794. "I find," he says, "that a ten years' abandonment of my lands to the ravages of overseers has brought on them a degree of degradation far beyond what I had expected. As this obliges me to adopt a milder course of cropping, so I find that they have enabled me to do it by having opened a great deal of land during my absence. I have therefore determined on a division of my farms into six fields, to be put under this rotation: 1st year, wheat; 2d, corn, potatoes, and peas; 3d, rye or wheat, according to circumstances; 4th and 5th, clover, where the fields will bring it, and buckwheat dressings where they will not; 6th, folding and buckwheat dressing. But it will take me from 3 to 6 years to get this plan under way. The maxim, 'Slow and sure,' is not less a good one in agriculture than in politics."

Landlords strive to sustain their Land.

The tenure of land, that is to say, the manner in which land is held, has often had an enormous influence upon the maintenance of fertility. A certain tendency to "run out" farms, which is noticeable in this country, while in Europe the rule is to "keep them up," doubtless depends in great measure upon the different tenures in the two countries. Wherever there are landlords and tenants, the former will look out more or less carefully for the permanent interests of the soil, but in this country there have practically been comparatively few people to represent the landlord's interest, for the attachment to localities is so slight, and land so abundant, that not many of our people have cared to consider whether their land was treated with absolute justice.

Fixed Rotations a Symptom of Conservative Farming.

In countries not given over to the commercial activity of modern times, in all easy-going countries, such as the England of a century ago or the Germany of thirty years since, there is a strong tendency for systems of husbandry, as well as everything else, to crystallize out into definite and seemingly permanent forms, depending upon the conditions and circumstances which obtain in the different districts. This fact is very well illustrated by the various systems of farming which were followed in England at the close of the last century, at the time when Marshall and Young travelled through that country and published their observations. It is manifest that at that time each special district had settled down into some one definite style of farming, which, while it kept the land from running out, and so satisfied the landlords, did at the same time afford profit to the farmer.

In many of the interior districts of England there were definite systems of rotation, varying as to their details according as they were based solely upon the dung of neat stock or of sheep, or upon the use of lime or marl in addition to the dungs. But in the vicinity of London there was even then, as has been said under the head of Rotation, no definite rotation of crops, and the system of farming was dependent upon manure obtained from the city, — and it had been so dependent time out of mind. Thus Marshall, writing in 1799, says: —

> "The course of practice in the Vale of London may be said to be altogether without regularity. What marks the practice of this part of the kingdom is, that the same lands, though in a state of enclosure and equally adapted to grain and herbage, have been continued, perhaps for ages, either under a course of arable management or in a state of perennial herbage, and have not been changed from grass to grain and grain to herbage, conformably with the practice of most other enclosed districts."
>
> "Improper as this plan of management would be in ordinary situations, where the land has nothing but its produce to depend upon for its support; it would be, under due limitation, perfectly right in the neighborhood of the metropolis, or of other large towns, where the herbage of old grass-lands, whether for hay or pasturage, is required, and where a supply of manure can be had to keep up the arable lands in sufficient condition without permitting them to renew their strength occasionally in a state of herbage."

In like manner there was not at that time any definite system of rotations in the more backward districts of England, where pasturage was the prominent business. In Yorkshire, at the close of the last century, Marshall could not find any regular course of crops. Sheep and cattle were pastured through the summer, and there was grass-land enough to provide hay for their winter support; but, as is the case to-day in most parts of New England, none of the grass-land was broken up until it had become unproductive.

Examples of Old English Farming.

Under the head of Rotation the system of husbandry practised in Norfolk County has already been described. It was grain, turnips, grain, clover, — the turnips and clover going to support fatting cattle, whose dung went to fertilize the grain-fields. In the Midland Counties of England a somewhat different system was employed. The soil there is a deep sandy loam, and the farms were devoted to grain, dairying, and cattle-breeding. The rotation was one from grass to grain, as has been mentioned. In fact, the system had some slight points of resemblance with that which now prevails in New England, except that most of the grass-land was pastured, only a comparatively small amount of hay being there needed in order to keep stock through the mild winters. The plan was, greensward for 6 or 7 years, followed by oats, wheat, and barley, then grass again. It may be regarded as the old Yorkshire, or the present New England practice, systematized and reduced to line and rule, though perhaps not very wisely, on account of the repeated grain crops.

All Forage should be put to Use.

It is important not to lose sight of the conception, that, wherever possible, a farm should be conducted in such manner that everything produced upon it may be turned to profit. This idea seems self-evident, but it is by no means always acted upon. In some parts of Ohio, for example, and the adjacent States, it commonly happens, even now, in the grain-growing regions, that very much more coarse forage is produced than there is any use found for. The farm animals are wintered on corn-stalks and straw, together with a little clover-hay and grain, though most of the hay is fed to working horses in the autumn and spring. But no pretence is made of using more than a small part of the straw, not even for bedding or for manure, and in addition to the straw there are large quantities of clover-stalks; for the second growth of clover is cut for seed, and the stalks are allowed to go to waste unfed and unused.

It would seem to the uninitiated that some system of turning

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these matters either into beef, or mutton, or wool, or merchantable dairy products, might be devised. Possibly, ensilaged cow peas, or a similar crop, or perhaps even ensilaged corn-stalks plus cotton-seed meal, might serve as complementary food to balance the straws. But the main point to be insisted upon is that the farms, i. e. the crops, appear to stand in need of being rearranged so that they shall all pull together, as it were.

New England Farms.

The farms of New England may be classed roughly, and speaking in general terms, either as milk farms or as sheep farms. A few cattle are still reared, though the old system of stock farms has practically been given up, because of the importation of cheap cattle from Texas and the West. Excepting those of choice breeds, the cattle now reared in New England come for the most part from wild bush farms of the crudest description.

The best New England farms are usually devoted to the production of milk to be sold as such, or to be converted into butter, or more rarely into cheese. Large quantities of hay, oats, and potatoes are sold as such, and in the vicinity of cities various garden crops are grown. There are exceptional districts given over to onions, or cranberries, or tobacco, and other special crops. In some places considerable rye is grown; in others, beans and peas. Sometimes small fields of wheat appear, and almost everywhere more or less maize.

Upon some of the milk farms small quantities of roots of one kind or another are grown. But beyond these things, the agricultural products of New England are meagre, and upon the whole the agriculture is backward and uninteresting, excepting special regions, such as the river intervales and the districts manured with seaweeds.

With the exception of the cases last mentioned, it is seldom that one can find what may be called well-balanced farms, where palpable advantage is taken of some natural resource, or where the round of operations is manifestly judicious.

Farms based on Water Meadows.

As has been said, it is a common thing in Europe to see farms based upon permanent irrigated mowing fields. Cattle are fed upon the grass, or winter-fed upon the hay, from these fields fertilized by water, and the dung of the cattle goes to manure the rest of the farm, which may thus be made to produce grain or potatoes, or some other crop for sale. This practice is a very old one, — so old, indeed, that everybody is supposed to know of it as a matter of course; hence less is said and written about it nowadays than would be well. It is interesting to observe that this method has come down directly from the time of common fields, and that it is perhaps the most conspicuous agricultural inheritance from that period.

It will be remembered that, in order to get manure for their grain-fields, the village communities maintained permanent water meadows, and wintered their cattle on the hay from these meadows together with the straw of their grain crops.

The success of the grain-fields, i. e. the prosperity of the village, practically depended on the size and quality of the meadow; and just so in after years many a European farm has prospered or deteriorated according as the water meadows attached to it were or were not large enough for its full support. Manifestly, if only its water meadow be large enough, a farm may be carried on indefinitely without need of buying in artificial fertilizers, or cattle food, or of hesitating to grow and sell exhaustive crops. Naturally enough, however, the tendency has been so to arrange farms that their meadows alone are not fully capable of supporting them. That is to say, it has been found more profitable, on the whole, to keep a part of the land which might well be meadow under the plough for the production of merchantable crops, and to make fallow crops, rotations, oil-cake, and artificial fertilizers play their parts towards keeping the farm in good heart.

It is evident, however, that even a small strip of water meadow may be made to do much for the support of a farm, by using its products judiciously in connection with other forage crops. In New England, the intervale farms do in some measure belong to this category. So, too, do the salt marshes of the seaboard, for they afford hay naturally without need of manuring. These marshes were very important adjuncts to the farms of our forefathers, and they played no small part in helping the early settlers to maintain themselves on this continent. We may even go one step lower and include the rough sedge-hay of fresh-water meadows; for there are numerous farms in New England that depend in good part upon such bog-meadow hay for wintering their stock. I have urged in the Bussey Bulletin, from chemical considerations, the importance of this hay, and it is evident from common observation that it has considerable value when properly used.

Indeed, it may be said of American farmers, that they have in general distinguished themselves chiefly by taking advantage of things lying at the surface. They have picked up many things that were lying in plain sight, but have seldom searched out and made full use of less conspicuous treasures. Ever since the country was settled, New Englanders have been cutting the natural swamp sedges, and have even had the face to call the product "meadow-hay"; but they have not exerted themselves to establish water meadows.

It is true that at one time, long ago, there was a tolerably emphatic movement toward the embanking of salt marshes here in Massachusetts, and large tracts of lowland may still be seen at Hingham and Cohasset upon which excellent crops of English hay were formerly grown year after year without thought of manure. But most of the embankments have been broken down by storms during the last 30 or 40 years, and the improvements wholly destroyed. A very large tract of marsh-land has been embanked recently at Marshfield, in this State, which would ultimately be highly valuable were it not that the proprietors are worried and disheartened by malicious depredations and lawsuits, as has doubtless often occurred in the history of such enclosures in other parts of the world. Miss Martineau wrote an interesting child's book, "Settlers at Home," based on the misfortunes of colonists upon the embanked marshes of the east coast of England.

When marsh land has once been embanked, and means have been provided for removing the water that drains out from it, some little time is required in order that the land may be freed so completely from salt and sulphides that all kinds of crops may be grown upon it. To facilitate the sweetening process, ditches are dug to receive the water that leaches from the soil, and care is taken not to plough the land very deeply at first. By growing grass and clover as soon as the land will carry these crops, the soil will the sooner become fit for supporting other kinds of plants. Or, best of all, whenever practicable, as on a small patch of marsh lying at the base of a hill, and in places where the marsh land is divided into compartments by cross dikes, the saline soil may be flooded with fresh water, after the draining ditches have been dug, and kept under water for several months, in order actually to dissolve out a good part of the saline matter from the soil.

One Advantage of Wild Pastures.

Even at the present day, it is noticeable that very many New England farms are in some part supported, much as the common fields of the village communities were, by wild grasses obtained from bog meadows, salt marshes, and pastures. There are comparatively few farmers among us who do not support certain parts of their estates by means of manure that has been derived from other parts. They take the surplus strength of the wilder lands and bring it to bear upon the cultivated fields. It is practically a mere matter of taking fertilizers from one place and bringing them to another; and it is to be noted that the system now in question is closely related to the common plan of feeding animals with the refuse of crops, such as straw, corn-stover, and beet-cake, as a means of getting manure to grow grain. So, too, when bran, brewers' grains, Indian corn, and oil-cake are bought for feeding animals, fertilizers are brought from other men's farms to our own.

The Milk Farms of Saxony.

A good example of a highly artificial arrangement is seen in the Saxon milk farms. Potatoes are grown freely in that country, and upon this crop farms are often based, as follows: — A stable of milch cows, whose milk is sold as such, or made into butter or cheese. Potatoes, as the chief crop, to be fermented and distilled to whiskey upon the farm, where the residue from the distillation (slop), together with straw, is fed to the cows through the autumn and winter. During spring and summer the cows are fed upon mown clover, and other green forage. Large quantities of dung are produced in this way in the course of the year, — enough to serve, not only for manuring the potato fields, but to give great crops of wheat, and rye, and rape-seed, all of which are sold off the farm, as well as the whiskey and the milk products.

Working upon this basis, the Saxon farmer is contented with a very small margin of profit, or even with no profit at all, from the milk and the products from milk. He keeps the cows primarily in order that they may manufacture manure out of the potato slop. Or, to look at the matter from another point of view, potatoes are grown in order to get manure for the grain. Practically, when such an establishment is working well, the farmer does get three profits, — one from grain, one from whiskey, and one from milk, — and he has, moreover, three strings to his bow. If the times are such that wheat yields no profit, money may still be got from the whiskey, and so conversely.

Products that remove no Fertilizers.

The foregoing example manifestly presents a definite, well-considered plan for a farm; i. e. a plan based on rational thinking. Just so, upon almost any European farm we can see tolerably clearly the principles on which the system of culture depends. The farmers strive also to produce such things as sugar from beet-roots; oil from rape-seed or linseed; spirit, or starch, or glucose, from potatoes and grain; and butter from grass; — all of which are non-nitrogenous products free from ashes. That is to say, the farmer's aim is to produce things which (when sold) shall not carry off fertilizing matters, and which shall leave residues, like press-cake, oil-cake, and slop, that are highly nutritious, and that yield rich dung. Arrangements such as these were devised long ago, before the days of artificial fertilizers, when the great desideratum was that the farm should support itself without need of buying manure. But it is usually hard to detect any good and sufficient reasons for the methods which are pursued upon the farms of New England.

There are doubtless some farms, based upon the use of peat composts, which are eminently philosophical, and which probably represent the best results thus far obtained in this region; and the like may perhaps be said of some small dairy farms where cattle are soiled, and of milk farms where rough fodder is reinforced with cotton-seed meal, or the like. But it cannot be said of either of these systems that they have become general, nor is it true that the use of peat compost has been reduced to a definite rule of practice.

Large Farms versus Small Farms.

It is difficult to discuss the subject of farms without making some allusion to the question of large farms versus small farms, which has greatly exercised the minds of statesmen and political economists in Europe. The question is really, What are the respective merits of farms dependent upon capital and worked as factories, and of farms occupied and worked by peasants or yeomen as mere homes? There is a great deal to be said upon both sides of the question.

There is something very attractive in the idea of a farm handled as a mere manufacturing establishment, in which, by laboring upon the raw materials, soil, and manure, we elaborate, with the aid of various natural forces, the desired crops. By operating in this large way, i. e. upon what is called the manufacturing scale, it is possible to apply scientific knowledge more directly than is usually practicable upon small farms, and to make use of the best implements and devices, such as draining and irrigation, for example. It is notorious withal, that every improvement thus far made in European agriculture has been developed by the large-way farmers, the peasants having simply followed where the larger proprietors led. All this, not of fundamental necessity perhaps, but because of the real weakness, narrow-mindedness, and sluggishness of the small farmers. But, on the other hand, the picture of the peasant proprietor supporting himself and his family in absolute independence upon a small patch of land has many pleasing features.

In favor of the large farms, it is argued that experience has shown that capital may be applied to farming, as well as to other employments, provided only there be room enough for it to act. It would be absurd, of course, to employ a skilful steward or overseer, at a large salary, unless there was a sufficient amount of land to occupy him fully, or, rather, to the best advantage. The analogy of other kinds of business teaches that, up to a certain point, there is an advantage in operating in the large way. Large farmers are generally rich farmers, i. e. they have command of capital; and, other things being equal, the rich farmer will be more likely to cultivate the land carefully and understandingly, and to put it to good profit, than the poor one. Throwing gardens out of the account, it is in point of fact commonly observed that large farmers have better crops as the general rule than small farmers.

Arthur Young long ago collected statistics upon this point. He found that the crops of the large farmers were in fact very much better than those of the small. One of the results of his inquiry shows, however, as might have been expected, that there is a limit beyond which increase of size ceases to be an advantage. Thus, while he found that English farms of from 200 to 400 acres were in his day better for live stock than smaller ones, in the average proportion of 5½ to 3½, they were more than five times better than the still larger farms that came under his observation.

Young's inquiry was directed to the comparison of the ordinary run of English farms of his time; he did not in this particular instance take into account the small peasant farms that are now so common in Europe. But it is to the consideration of these last that the discussions among politicians have been mainly devoted.

The peasant farms have an enormous advantage over the large farms in respect to the cost and the quality of labor. Farm labor, in order to be applied to the best advantage, should not only be executed with judgment, but with interest and devotion. The peasant takes the field with his wife and children, and not only utilizes much labor that would have no merchantable value, but he has always an eye to the judicious and constant application of the labor. The cost of the labor applied to his land is consequently low, while the effect produced by it is great. Herein, the peasant is specially favorably circumstanced as compared with the large-way farmer, whose hired laborers have comparatively little interest in their work, and who cannot be subjected to anything like the oversight that is constantly present, as a matter of course, upon the peasant farm. It is from this cause more particularly that, in regions where peasant proprietors abound, the produce of the large farm suffers severely in the markets from the competition of the peasant's crops. This statement is particularly true of backward countries like France, where there is no great demand for labor in the occupations other than farming. Wherever machines can be used with advantage, i. e. in countries where labor is scarce and in demand, and land cheap, the peasant's hand-grown crops would be dearer than those of large farms.

What is a "large" Farm?

There has been at one time and another a certain amount of discussion as to what should be understood by the terms "large," "medium," and "small farms." Some writers have classified farms from the number of ploughs. For these writers, "three ploughs" means a large farm, and "two ploughs" a medium-sized farm, while a farm using no plough at all would be small. Other writers have classified farms by the number of acres. For them anything over 300 acres would be called large, while farms containing from 100 to 300 acres would be medium.

Other observers have maintained that neither of these definitions is sufficiently precise. They have suggested that a large farm is one that cannot be directed by a single man, and a medium farm one that can be directed by one man, though that man will have no time at all to work himself; while every farm that is carried on by the members of a family should be called small. This last definition is probably the best. At all events, it justly disposes of the average New England farm by relegating it to the same class with the farms of peasant proprietors.

As a general rule, to which there are of course some exceptions, it may be said, that, as farms pass from those which may be classed as gardens to those which are really large, less and less human labor needs to be employed for the cultivation of them.

Farming without Live Stock.

One desideratum at the present time, in certain localities, is to be able to farm profitably without keeping much live stock. Upon really good land, competent to produce valuable products, the artificial fertilizers permit the farmer to do this, provided the farm and the crops are so arranged that little or nothing shall be produced which is not directly salable. In general, it is the production of rough or refuse forage, and the existence of rocky or hilly pastures and low-lying marshes or meadows, which necessitate the keeping of cattle, much more than any need of their dung. If corn stalks and bog-meadow hay, or clover even, are harvested, cattle must be kept to eat them lest they go to utter waste.

Still, a certain amount of farmyard manure is a very useful basis of operations, particularly for the amelioration of certain soils and the growing of some kinds of crops, and the problem really is how to supplement with artificial fertilizers the least amount of dung that can be used profitably, rather than how to get along without any dung. Since farmyard manure is not perfect, but in need of being supplemented with one or another kind of special fertilizer, according to the several classes of crops that are to be grown, it will manifestly be more philosophical, whenever the comparative price of fertilizers and dung will permit, to apply the dung in quantities smaller than those indicated by tradition, and to reinforce it with such additions of the special fertilizers as may be needed. It is precisely because of the want of just proportion in farmyard manure, that the purchase of small quantities of bone-meal to be applied to turnips, of Stassfurt salts for cabbages, or of nitrate of soda for wheat, may in many situations be better and more economical farming than the buying of fodder wherewith to maintain a larger herd or to make better dung. To each and to every farmer the question is continually presented anew, How many, or rather how few, cattle shall be kept, in order to the best advantage of myself and my land?

The Question of selling Hay.

To the mind of the average New Englander, the selling of hay from an inland farm is a wellnigh criminal offence; but from the modern, and particularly from the chemical point of view, such selling of hay is a most commendable practice, provided only that the hay brings a proper price, and that the farmer uses some part of the money thus gained to replace the chemical substances which the hay crop has taken from the land. For many parts of New England at the present time the chief crop to be aimed at is merchantable hay. Only it needs to be obtained at small cost. Ordinarily such hay is got either from bottom lands or from moist slopes that are manured naturally by the ground water; or it is grown by means of dung obtained from animals that have been fed in some part on bog-meadow hay, or other unmerchantable product, reinforced with shorts, or corn meal, or cotton-seed meal.

The proper ways of getting hay in this region, without cattle, would seem to be artificial irrigation and peat composts reinforced with small additions of bone-black, floats, Stassfurt potash-salts, or wood ashes. It would appear that only materials of low cost can be used, and that composts should be home-made. There are probably few situations in New England where it would be remunerative to use costly fertilizers for producing hay alone. Unless some salable interpolated crop can be got by means of the fertilizers, the latter should either be let alone upon a hay farm, or used with very great caution. It is well understood in this vicinity, that, as things are now, it is quite out of the question to get a profit from hay by means of the ordinary run of commercial fertilizers, applied directly to the grass.

In the vicinity of Boston the hay farmer suffers all the while from the competition of hay grown upon the intervales of the Connecticut River and its tributaries, i. e. hay grown by irrigation at little or no cost for manure; and he has to compete also with hay from wild farms in the State of Maine, where numberless small crops are harvested every year, at very small cost, from very cheap land, to which little or no manure is ever applied. The comparative abundance of moisture in the soil of that region of fogs and forests enables the farmers to cut grass in this way year after year.

An interesting method of keeping up hay farms in the region about Boston consists in taking pleasure-horses to board during the winter months; that is to say, instead of hauling hay into the city for sale, and hauling out manure to spread upon the grass fields, the plan is to take in horses enough to consume the hay at the farm, and to apply their dung to the land. The price of board is such that the hay is sold at a higher rate than could be got for it as hay, while the fertility of the farm is maintained.

CHAPTER XVII.

GENERALITIES AS TO THE GROWTH OF CROPS.

THE reasons which go to determine the cultivation of any one kind of plant in a given locality, or upon a given farm, as well as those which cause other kinds to be neglected, could be best considered under the separate heads of each special crop. But there are certain general considerations, nevertheless, which may well be treated of together.

Movements of Matters in the Plant.

Thus, the passage of the various constituents of a plant from one part of it to another, as the plant advances to maturity, is a capital fact common to all plants, though perhaps different as to degree and method in each and every different kind. When a seed germinates, many of the matters in the seed pass from it into the roots and sprout, in order to form these organs. So too, after the act of germination has been completed, and the plant devotes its energies, first to the development of roots, and then to the development of leaves, the same rule holds good, and the workings of it are particularly conspicuous after these organs of assimilation have been perfected, and the forces of the plant are seen to be devoted more especially to the formation of flowers and fruit and seeds, or to the production of fleshy roots, or of buds for next year's use.

In autumn, the more valuable contents of the mature leaves of trees pass back into the tree itself, and contribute to the equipment of the buds from which the new leaves of the coming year are to start; while the dead leaf that falls is a mere skeleton, as it were, of woody fibre, that contains but little either of nutritive or of fertilizing matters. It is true not only of trees, but of most plants, that during the final, ripening period, as indeed through each of the successive stages of growth which have preceded it, matters pass freely from one part of the plant to another, for building up and nourishing the various organs. Naturally enough, these movements are more conspicuous at some stages of development than at others. During the growth of the leaves, for example, whose function is to elaborate the crude inorganic constituents which are taken in from the air and the soil, more matters are needed in the leaves than elsewhere. But when the leaves are finished, then their constituents are free to be used for other purposes, and we see in fact that the oldest leaves gradually wither and die as they give up to the newer parts of the plant many of the matters that were contained in their cells.

This migration or translocation of the constituents of plants is true not only of the various inorganic or ash ingredients, but of many of the organized matters as well. Several of the "proximate constituents" of the plant, notably albumen, starch, and oil, are moved about from one part of the plant to another, as occasion may require. It may well be true, indeed, that some of the ash ingredients are translocated only by virtue of the fact that they form a constituent part of the organized matters.

Since the movements of the ash ingredients admit of being rather more easily studied than those of the organized matters, chemists have hitherto been apt to lay special stress upon this branch of the subject, although it is manifest that the movements of the organized matters are really of most importance.

Translocation of Matters in Ripening Grain.

There are many familiar facts that enforce the practical importance of attending carefully to the study of these changes in position of the components of plants. It is known, for example, that the young shoots of rye, or oats, or wheat, or barley, are exceedingly nutritious fodder, and that they are greedily eaten by animals; but, on the other hand, the straw of these several plants, that of oats perhaps excepted, does not attract animals at all, unless they are very hungry, or unless they have been trained to eat straw, or unless, as the common saying is, they find opportunity to steal it. It is known, too, that in the life of every grain crop there comes a time when the plants "stop growing," and "begin to ripen their seeds." In other words there comes a time when the plant ceases to draw food from the air and from the soil, and devotes itself to the process of concentrating in the seed the nutriment that was previously scattered through all parts of the plant.

Pierre found, on studying the development of wheat plants, that the amount of dry organic matter in the plant reached its highest point some 15 or 20 days before complete ripeness; after which time the amount of matter lost from the plants by oxidation (respiration) was larger, or at the least no less, than that gained by way of assimilation; but at this very time the matters in the plants continued to move freely out from the leaves and straw into and towards the seeds.

After-ripening of Grain.

Even when a plant is cut down while its seeds are soft and milky, there will still be the so-called "after-ripening," provided the seeds are allowed to ripen in connection with the stem, and to draw nourishment from it. But all these facts are mere consequences of the transference of various constituents of the plant from one part of the plant to another, and they illustrate very forcibly the arguments directly to be set forth.

When to harvest Crops.

It is from a knowledge of the laws that control this transference of matter that just conclusions may be drawn as to the times of harvesting crops, and as to the manner of treating a crop according as it is intended to be used as grain or as forage. It may seem absurd to many persons, perhaps, to insist that the discovery of a scientific principle like the one now in question, the knowledge of which dates but a few years back, has taught to farmers some highly important lessons as to the times and seasons at which crops may best be gathered. But it is unquestionably true, that this discovery has given precision and definition to several matters which were previously not a little obscure.

The example well illustrates the difference between empirical and scientific knowledge. There must always have been numerous farmers who had learned from personal experience just when to gather grass or grain in order to the best results, and the example of these sagacious persons must have been followed more or less closely by their neighbors. But so long as the experts had no sufficient reason to offer for their practices other than that they knew their way was the best way, they were subject to criticism and animadversion, and their methods could hardly ever be universally accepted. In point of fact, the times of harvesting did differ appreciably in different localities, and it was not until chemical analysis had taught the composition of the crops at the different stages of their growth that any one really knew just what was right and proper to do in the matter of gathering grain or grass.

The importance of knowing when to harvest a crop is seen most conspicuously in the improved methods of making hay that are now in vogue. There was a time, not very long ago, when much of the hay crop of New England was left standing until it was mere straw; the argument being that grass "shrinks" excessively when cut before it is "ripe." On the other hand, at the time of my first visit to Germany, in 1855, I had opportunity to listen to Stoeckhardt's presentation to Saxon farmers of the to them novel idea that rowen hay is a valuable food for cows. They had previously-entertained the notion, that rowen must be wellnigh worthless as cattle food because it is immature. They contrasted it with full-grown hay to its disadvantage, much as a laboring man would contrast veal with beef. But these men were among the very best farmers in Europe. I was the more impressed with this example, because familiar with the high estimation in which rowen was held at that time by New England farmers.

Researches as to the Times when Translocation occurs.

The investigation of the times and seasons when matters are transferred from one part of the plant to another has thrown considerable light on the theory of rotation also, and on the question of the exhaustion of land. It was thought at one time by many practical men that crops do not really exhaust the land, excepting at the times when their seeds are forming, i. e. between the moment of blossoming and ripening. This idea was based in part on the palpable fact, that in a given weight of seeds there are contained more nutritive matters than in any other part of the plant, whence it was not wholly unnatural to conclude that a great deal of nourishment had to be taken in by the plant during the formation of the seeds. But probably the chief reason for the belief was the familiar fact that crops which are mown in blossom impoverish the soil much less than those that are left to ripen. Clover and vetches, for example, had long been considered to be non-exhaustive, or even decidedly ameliorating crops.

This opinion as to the exhaustive character of ripening crops was combated by the noted French agricultural writer Dombasle, who argued that the formation of seeds, and indeed all the work of organization that occurs in a plant after the time of flowering, depend solely on the store of matters that have been accumulated in the plant previous to that time. To him it seemed plain that the young plant accumulates food in such large quantities, that, at the time of flowering, it has become a reservoir full of materials proper for the formation of the seeds.

He dwelt on those facts of practical experience which go to show that plants take as much food from the soil at the beginning of their development as they do when their growth is more advanced. Among crops reputed to be highly exhaustive, he cited several, such as cabbage, tobacco, and woad, which do not bear seeds; and he urged the well-known rapid loss of fertility in seed-beds, where young beets and rape are started. He maintained that the reason why certain green crops are non-exhaustive depends upon the fact that they leave in the soil a great mass of roots, which is not only large as compared with the total weight of the crop, but also as compared with the residue left by other plants which have been allowed to draw "juices" from their roots while ripening their seeds.

In the year 1844, towards the end of June, Dombasle marked 40 wheat plants that were in blossom, and took up 20 of them, while the other 20 were left to complete their growth. After having been dried, the first lot was found to consist of 43 grm. roots and 126 grm. stalks and leaves, or all together 169 grm. Two months later, when the crop was harvested, he collected the other 20 plants, and found that they contained 27 grm. roots, 86 grm. stalks, leaves and chaff, and 67 grm. grain, or together 180 grm. Whence it seemed to appear that in two months' time the twenty plants had gained no more than 11 grams, or about $\frac{1}{16}$ their total weight. In other words, his experiment seemed to show that the plants had accumulated, previous to the moment of flowering, $\frac{15}{16}$ of their final weight. It was evident withal, that, if the wheat had been mown when in blossom, an amount of matter equal to one quarter the weight of the harvest would have been left in the earth in the form of roots, while the ripe plants would have left in the soil no more than one seventh the weight of the sheaves.

Almost simultaneously with Dombasle, Boussingault urged, as a fact of observation, that plants which have been pulled up out of the earth after flowering will still perfect seeds, if they are kept properly moistened, although they have no connection with the soil. He stated that he had himself seen oat plants bear a small number of well-formed seeds when taken from the soil at the time of blossoming, and thereafter kept with their roots in distilled water. From all of which evidence, as he urges, there can be no doubt left that substances such as sugar, starch, and albuminoids, which have accumulated in the plant previously to the moment of the fecundation of the flowers, do gradually pass out from the roots and leaves and stems, towards the place where the fruit is to be developed. Meanwhile the green color of the leaves is seen to fade gradually, in consonance with the movements aforesaid.

A similar experiment with oat plants was tried long afterwards by Heinrich, who took up some of the plants from a dry sandy soil when they were in blossom, carefully washed off the adhering earth, and placed the roots in a jar of distilled water. The plants thus treated ripened sooner than those left standing in the field, though the seeds they bore were lighter than the field-grown grain; and it was in evidence that nearly three quarters of all the matter necessary for the formation of the seeds had been taken into the plants by the time they came into flower. It is a fact of familiar observation withal, that really mature clover or beet plants, such as have borne seeds, can no longer be regarded as fodder, since they now consist almost entirely of residual, tasteless woody fibre.

But Boussingault did not hesitate to urge that the results of Dombasle's experiments must have been altogether exceptional, and that plants do continue, as a general rule, to assimilate matters from the air and the soil, even after the time of flowering. It is now known, in fact, as regards this matter, that much depends on the weather, and on the condition of the soil in which the plants are standing. When moisture and food come to a crop, even tolerably late in life, they may cause it to grow with considerable freedom.

If Dombasle's conclusion were strictly true, viz. that a crop mown in flower contains almost the whole of the organic matter which it is capable of accumulating, and that it then affords about as much nutritive matter as it would if left to ripen some two or three months later, the inference would logically be drawn that it might often be more advantageous to mow crops when they are green, and to use them as fodder, rather than to wait for the grain to ripen. For by proceeding in this way it would be possible to sow and to mow two crops upon the land in a single year.

To test the matter, Boussingault chose wheat plants from a field, as Dombasle had done, but he collected a much larger number (450) at each of the stages of growth, and he subjected them to analysis after they had been dried and weighed. The results of this interesting research are given in the following tables.

450 plants collected on the 19th of May, 1844, yielded, —

Air-dried stalks and leaves	277	grams.
" roots	46	"
	323	"

On the 9th of June, when beginning to blossom, —

Air-dried ears in bloom	111	grams.
" stalks and leaves	850	"
" roots	100	"
	1,061	"

On the 15th of August, at the time of harvest, —

Air-dried grain	677	grams.
" chaff	155	"
" straw	928	"
" roots	121	"
	1,881	"

It appears from these figures that between the beginning of blossoming and complete ripeness the plants had nearly doubled their weight (100 : 177), which is a very different result from that got by Dombasle.

The crop actually harvested from Boussingault's field was at the rate of 1,685 kilos of grain, and 2,681 kilos of straw and chaff, to the hectare; and there were 300 kilos of roots, according to the best estimate that could be made; — in all, 4,666 kilos.

From the analyses of the selected samples, and analysis of the seeds sown, the following table was calculated. It shows the weight in kilos of matters obtained from the crop grown upon a hectare (2.5 acres) of land.

Dates at which the Plants were collected.	Dry Plants.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
19 May	689	257	40	354	12	26
9 June	2,631	1,008	163	1,371	24	66
15 August (harvest)	4,666	1,736	317	2,324	42	187
Increase from 19 May to 9 June	1,942	751	123	1,017	12	40
Increase from 9 June to 15 Aug.	2,035	728	154	953	18	121

Thus it appears that, while 751 kilos of carbon were assimilated between the 19th of May and the 9th of June, before the time of flowering, there were 728 kilos of carbon assimilated between the 9th of June and the 15th of August, between flowering and ripeness. 12 and 18 kilos of nitrogen respectively were assimilated in the two periods. If it be assumed that the wheat grew continually from the 1st of March to the 15th of August, the rates of increase may be stated as in the following table.

Times of Growth.	No. of Days of Growth.	Kilos gained per Day and Hectare.			
		Dry Organic Matter.	Carbon.	Nitrogen.	Ash.
1 March to 19 May	79	6.82	2.75	0.12	0.28
19 May to 9 June	21	92.95	35.75	0.54	1.92
9 May to 15 August	56	36.34	13.00	0.33	2.16
Mean assimilation per day and hectare		28.95	10.88	0.25	1.18

It is now known that, during the first period of growth, plants devote themselves particularly to the production of roots, hence the comparatively small amount of matter produced above ground in this experiment. The explanation of the great gain of carbon and dry organic matter during the latter half of May, when the stalks of the wheat were shooting, will be set forth hereafter, under Oats. Boussingault concluded from these results, justly enough, that while there could be no doubt that assimilation was very rapid in the younger plants which he examined, or that it gradually diminished as the plants approached maturity, it was none the less true that the plants did produce, i. e. assimilate or take in from the air and soil, a great deal of matter after the time of flowering.

In other words, it may be said once more, that the plant is occupied at first with the work of developing roots, then with the growth of the vegetative organs, then with the formation of flowers, and finally with the perfecting of fruit, or, in the case of biennial plants, with the storing up of a reservoir of provision, as in roots and tubers for next year's use; and that at each of these several stages most of the work done relates to the chief purpose of the period, though the lines of demarcation between the periods are seldom clearly defined, and some work proper to the earlier periods is still done during the later stages of development.

It should be said that Boussingault collected materials for a similar study of a leguminous crop, viz. beans; but the increase of vegetable matter produced in this case after the time of flowering was so very large, that he deemed it wholly unnecessary to resort to analysis to put the fact in evidence.

Translocation during Germination.

An excellent illustration of the kinds of changes which occur when matters are translocated in plants is seen when a germinating seed throws out its roots and sprout. If there was oil in the seed, it changes to soluble mobile sugar, which moves to places where it is needed, and is there changed to new substances; to cellulose, for example, for building the sprout, or, at a later stage, it may even change back to oil, if need be. Starch changes to sugar also, and albuminoids change to amids or to peptones, as will be explained directly.

So, also, when a plant begins to grow independently of the seed, and to obtain food from the air and the soil, organic matters such as sugar and amids are sent down from the leaves into the roots for their nourishment, while ash ingredients, water, and nitrogen compounds pass up from the roots for the support of the entire plant. In general, soluble amids that come from albuminoids, and soluble sugar that comes from starch or oil, are specially prominent, considered as materials for the formation of new cells and new contents of cells. In all such changes, however, some part of the original matters in the seed are lost through processes of oxidation and evolution of carbonic acid, so that the weight of the new roots and sprout is considerably less than the weight of the seed, sometimes as much as one half less.

Migration of Special Substances.

With regard to the translocation of individual substances, it has been proved that albumen, and the allied matters called albuminoids, are moved from the leaves of grain plants through the stem into the ear, where they accumulate in large quantity; and that starch also is moved about freely from the leaves and stalks to the seeds. It is probable that gum is moved about in a similar way, and perhaps cellulose even, to a certain extent.

The movements of albuminoids are specially interesting, both because of the great importance of these substances, and because of the apparent difficulty of translocating them. They are "colloid" bodies, such as can only pass very slowly and with great difficulty through membranes like those which form the walls of plant cells. But it has been perfectly well made out, that, in order that they may be moved from one part of the plant to another, they are changed to the condition of amids, such as asparagin, leucin, tyrosin, glutamin, or the like. These amids are crystalloid bodies, and, unlike the colloid albumen, they can pass readily by osmose through the cell walls, and so reach the places where albuminoids are needed. There they are changed back to the albuminoid condition.

These changes have been well studied in the germination of certain seeds. When the seeds are exposed to warmth and moisture, chemical reactions set in; and among these reactions is one whereby some of the albuminoids of the seed are changed to asparagin (or the like), which is easily soluble and diffusible, and so passes readily into the young sprout of the plant. Both asparagin and leucin have been found, for example, in young pea and vetch plants that had just started from seeds.

Asparagin was first discovered, at the beginning of this century, in asparagus sprouts, having come to them out of the roots or rootstalks, instead of directly from a seed. It is now known that considerable quantities of amids are always stored up towards autumn, as a reserve of nitrogenous food, in root-stalks and tubers, such as those of the potato, and in root crops as well. Next year, when the roots are planted for the sake of getting seeds, the amids serve at once to nourish the young sprouts and rootlets. It is evident enough that the amids have a highly important part to play in the physiology of vegetation. They form most abundantly in those parts of plants where growth is most active, and are changed to albuminoids after their translocation.

Probably there are other ways also in which some part of the albuminoids may move about in the plant. Schumacher has noticed, indeed, that when albumen is mixed with phosphate of potash its rate of diffusion through membranes is considerably increased. There is good reason to believe that such a mixture might pass from one part of a plant to another much faster than albumen could pass by itself. And, as Pfeiffer has suggested, it is possible that an albuminoid insoluble in water, such as legumin, for example, might be dissolved by phosphate of potash, and in this state pass through the walls of cells until the place destined to receive legumin was reached, and there the legumin might be deposited in mass simply by the withdrawal of the solvent phosphate.

Simultaneous Movement of Phosphates and Albuminoids.

Inasmuch as it is well known that phosphoric acid passes out of the stalks and leaves of plants into their seeds, and accumulates in the seeds just as the albuminous substances do, it is a not unnatural inference that the movements of the two substances may be interdependent, or in some way connected. Indeed, the idea that some sort of connection exists between the movements of phosphoric acid and albuminous matters is a tolerably old one. It had been talked about long before the publication of Schumacher's observation.

One point that was adduced as evidence in support of the idea is the fact that in fruits and bulbs which contain much starch and but little albuminous matter there is but little phosphoric acid; while, as was just now intimated, those plants and parts of plants that are richest in albuminoids likewise contain the largest proportion of phosphoric acid. The potato, for example, well illustrates this point. It contains on the average about 2% of albuminoids, and less than 0.2% of phosphoric acid, while horse beans, with their 25 or 26% of albuminoids, show nearly 2% of phosphoric acid.

From observations such as these it was argued, some years since, that the amount of nitrogen assimilated by a plant probably stands in some very simple proportion to the amount of phosphoric acid taken in by the plant, and has an intimate physiological connection with this phosphoric acid. Several instances were recorded in which this proposition seemed to hold good, particularly in respect to the seeds of the plants that were examined. Thus Mayer found in oats and wheat and barley the relation 1 P_2O_5 to 2 N, very nearly; while in rye it was 1 : $2\frac{2}{10}$, in peas 1 : $3\frac{7}{10}$, and in beans 1 : $3\frac{4}{10}$. Fittbogen contrasted light and heavy barley as to this point. He divided a quantity of the grain into 7 different parts of as many different specific gravities, and found that the proportion of P_2O_5 to N varied between 1 : 1.82 and 1 : 2.43, though with no great regularity. In ripe barley grown to perfection in pots of sand he found the proportion to be 1 : 1.66; and in the unripe grain it was 1 : 1.72. This idea of fixed proportions has often been disputed, notably by Siegert, who has declared that P_2O_5 and N do not bear any constant relation to each other, either in wheat or rye. He found, too, that nitrogenous fertilizers increase the percentage of nitrogen in these grains, and diminish the percentage of phosphoric acid.

It is not improbable that albuminoids may be transferred from one part of a plant to another in both the ways that have been indicated above. Sometimes they may move, as such, with the help of phosphates; though more commonly they are passed about by being changed to diffusible amids that are subsequently reconverted to albuminoids.

It is probable, moreover, that albuminoids, and starch also, may be changed to mobile substances within the plant by processes of digestion and fermentation analogous to those which occur in the bodies of animals. The study of insectivorous plants has shown that such plants secrete acid juices, which digest and dissolve the edible portions of the insects, and in many plants unorganized ferments have been detected which when in presence of acids are capable of changing albuminoids to peptones, which are readily soluble and diffusible. Some of these ferments can change starch to sugar also.

It is generally felt nowadays that much more knowledge must be acquired in respect to the kinds and amounts of the several different albuminous matters in plants before anything definite can be said or believed as to the relations which subsist between phosphoric acid and these substances, either in general or in respect to any particular one of them.

It may be added, that Arendt, in examining oat plants, found that, although the rates at which phosphoric acid and nitrogen were assimilated were not constant throughout the entire life of the plants examined by him, there was nevertheless a decided tendency towards the proportion 1 phosphoric acid to 4 nitrogen which was the one found in the ripe plants. In oat seeds the proportion found by Arendt was 1 : 3. But his plants are known to have been exceptionally rich in nitrogen, and his results support in this respect the statement of Siegert, above mentioned.

Arendt found, nevertheless, that phosphoric acid passed continually, and in large quantities, into and towards those organs in which albuminoids were forming or to be formed, in spite of the fact that when once formed the albuminoids are quite independent of phosphoric acid for their continued existence, or at all events need only a very minute quantity of it.

Wetzke has tabulated as follows the results obtained by Heiden, Voigt, Güntz, and himself, as to the proportion of nitrogen to phosphoric acid in seeds according as the crops were manured with one or another kind of fertilizer. For each part of phosphoric acid in the seeds there were found the following parts of nitrogen: —

	Oats. 1869.	Oats. 1870.	Oats. 1871.	Rye. 1873.	Rye. 1875.	Rye. 1877.	Vetches. 1872.	Peas. 1876.
In the seed sown . .	2.53	2.45	1.70	2.13	2.01	2.18	4.86	4.94
No manure . . .	...	...	...	1.56	1.83	2.09	5.76	6.07
No manure . . .	1.78	1.76	1.82	1.67	1.96	2.29	6.75	5.28
Lime	2.31	2.94	1.52	1.44	1.90	2.11	6.56	4.00
Sulphate of ammonia	2.50	1.20	1.83	1.70	1.80	2.67	6.35	4.01
Phosphate of lime .	2.83	1.68	1.67	1.46	1.74	2.29	4.67	5.55
Sulphate of lime . .	2.17	1.62	1.16	1.80	1.93	2.21	6.73	6.05

Although there are wide variations, it appears that the nitrogenous fertilizers tend to produce grains rich in nitrogen in the case of the cereals, while they do not in regard to leguminous plants. With the legumes the phosphatic fertilizers seemed to diminish the proportion of nitrogen in the seeds.

Movements of Phosphoric Acid.

The movements of phosphoric acid from one part of the plant to another are very remarkable. Indeed, this substance is the most mobile among all the inorganic constituents of the plant. The facility with which it moves about is very much greater than that of the nitrogenized matters. As regards the oat plant, Arendt found phosphoric acid passing continually from the lower parts of the plant into the upper parts, especially after the time of flowering. The upper leaves and the stem gave up at least five sixths of all the phosphoric acid they had accumulated, and sent it into the ears. A very large part of the phosphoric acid in ripe grain has thus been moved from the leaves and the stem, after having once come to rest, as it were, in those organs. One thousand oat plants contained in their several parts, at the stated seasons, the following amounts of phosphoric acid, in grams : —

	3 lower Leaves open, 2 upper Leaves closed.	Not yet fully headed.	Just after Blossom.	Beginning of Ripening.	When Ripe.
3 lower joints of stem . .	0.47	0.20	0.21	0.20	0.19
2 middle joints of stem .	...	0.39	1.14	0.46	0.18
Upper joint	...	0.66	1.73	0.31	0.39
3 lower leaves.	1.05	0.70	0.69	0.51	0.35
2 upper leaves	1.75	1.67	1.18	0.74	0.59
Ear	...	2.36	5.36	10.67	12.52

It is probable that the phosphoric acid, or rather the phosphates, which pass thus freely from the leaves and stalks towards the ear through the entire life of the plant, and which accumulate so abundantly in the seeds, have several physiological functions to perform, in facilitating the transference of other kinds of organized matter besides albumen. It is known, for instance, that there are certain phosphorized fats and oils which tend to accumulate in small quantities in many kinds of seeds.

The Acid Juices of Plants.

The development of vegetable acids within the plant, and the changes they undergo, are subjects of no little interest, though they could be more conveniently discussed, perhaps, when considering the ripening of fruit, than in the present connection. It is noticed, for instance, that a good part of the tartaric, malic, oxalic, and other acids in leaves and in unripe fruits change to sugar as the fruits become ripe. So long as the acids themselves exist in the plant, they are held in combination, i. e. usually and for the most part, as acid salts by potash, soda, lime, or magnesia, while the sugar into which the acids are finally converted has apparently no need of the presence of potash or any other base. It has been thought, indeed, that when grapes ripen the proportion of potash contained in them diminishes. It follows necessarily, that, for the case now in question, potash, or some other base, is really essential for the formation of the sugar from the acids at the time of ripening. It was thought at one time, that even the power to move starch within the plant, which compounds of potash are known to possess, might be explained in some such way as this; but various difficulties have presented themselves to discredit this idea.

Movements of Starch.

It is known that starch, as well as the albuminoids, is moved from the leaves into the fruit, where it often accumulates in large quantities; that it is first organized in the leaves, and that it passes thence into and towards the fruit, being made soluble in some way within the cells, and dissolved to such an extent that it can pass little by little through the cell walls by way of osmose, and again change to true starch on occasion. It is known that potash does in some way play an important part both in the organization and the translocation of starch, and it has been proved that potash does not act by virtue of its alkalinity. At all events, none of the other alkalies are competent to take its place.

In the absence of potash, plants will not grow, and starch will neither form in them nor move in them, no matter how much soda, lithia, cæsia, or rubidia may be offered to them. Some lime is needed as well as potash, and so is a minute proportion of chlorine, in order that starch may move. The action of chlorine in aiding the movement of starch is akin to that of iron in developing the green grains of chlorophyl, in that an extremely minute amount of it is competent to do much work. As has been said already, the leaves of plants are white in the absence of iron, and not green. By means of the microscope, observers have seen the chlorophyl grains begin to grow and continue to prosper as soon as they gave a little iron to plants that had previously been deprived of that element.

As for chlorine itself, it is not disposed to accumulate in one part of a plant more than in another; nor does silica move about with any freedom; on the contrary, it remains wherever it may once have become fixed. Lime, also, seems to be tolerably equally distributed in all parts of the plant.

Movements of Potash.

Potash is, in general, rather evenly distributed throughout the plant; but it has been noticed that it seems to pass slowly out of grain into the straw at the time when the grain is ripening. At all events, this backward movement is true of the oat plant, in which Arendt found more potash in the stem than elsewhere. The maximum of potash was in the lower part of the ripe stem, and above this point the proportion of it diminished as the plants were older.

Both Arendt and Bretschneider have observed that no more potash is fixed by oats after the grain has begun to ripen. According to Arendt, the maximum of potash in the ears was at the time of blossoming; after that time, the proportion of potash in the grain diminished, while the proportion of magnesia increased. The movements of potash in wheat plants has been studied in no little detail by the French chemist Pierre. (Hoffmann's Jahresbericht, 1875–76, p. 304.)

Movements of Magnesia.

Magnesia passes from the lower stem to the upper parts of the plant, and increases constantly in the grain. It does not appear, however, that lime moves, i. e. accumulates, upward. Arendt found that, in oats, lime tended to pass out of the grain, as it were, as it ripened, and to be replaced by magnesia. He found also that the leaves were much richer in lime than in magnesia. Some of the proportions were as follows:—16 : 3; 16 : 2; 17 : 2. And, in general, there were 5 or 6 times as much lime as magnesia in the leaves. But in the stem the relation between the two bases was usually 1 : 1, or 1 : 1½, and on only one occasion did he find twice as much lime as magnesia. A similar remark is true of the ears; and in the ashes of the ripe grain there was more magnesia than lime, as has repeatedly been observed by other analysts. All these items of information mean something, of course, although no one has yet discovered what their meaning is.

Sulphur, which is taken into the plant in the form of sulphate of lime, sulphate of magnesia, sulphate of potash, or some other sulphate, goes to form an integral part of the albuminous matters in the plant, and of course moves about with these albuminoids towards the uppermost parts of the plant, and towards the grain and fruit.

Where Ash Ingredients do their Work.

It may be said in general of the ash ingredients, that their work is at the extremities of the plant. It is in the leaves and young stems, and in unripe seeds and fruit, that the largest proportions of ash ingredients are found under the ordinary conditions of growth, where there is no excess of soluble inorganic materials in the soil. In old wood, on the contrary, the proportion of ashes is comparatively small.

It appears, therefore, that in the economy of nature a very small proportion of inorganic materials is sufficient to perform the physiological functions necessary for the growth of plants; and this fact has indeed been fully proved by experiments on the growth of plants in water and in sand.

Accidental Ash Ingredients.

It is true that plants will, on occasion, take in a far larger quantity of ash ingredients than they have any use for. Of some things, such as potash, soda, and chlorine, they can carry without injury more than ten times the quantity that would be sufficient for their perfect growth. But there is always a limit to a plant's power of supporting the presence of an excess of inorganic matter; and the health of a plant may easily be disturbed by some kinds of ash ingredients as soon as any undue quantity of them has been taken up.

The foregoing remark may perhaps need to be qualified in so far as it applies to silica; for the amount of this substance that can be supported by some kinds of plants is little short of appalling. There is no suggestion either of limit or of regularity as to the amount that such plants may take in. Ashes have sometimes been found to contain more than 70% of silica, while in other instances only traces of it could be detected. There are, however, numerous plants which appear to have no use whatever for silica, and even maize has repeatedly been grown in the absence of it.

Indeed, Jodin has recently grown, by way of water culture, four successive generations of maize plants, which got no silica other than that from dust in the air, or from the substance of the vessels which held the solutions in which the plants grew. The silica was, in fact, reduced to an extremely minute trace, without any injury to the normal development of the plants. As a result of numerous experiments of similar tenor, a feeling has become somewhat general that it is hardly possible that silica can have any direct or conspicuous part to play either in the formation or the moving of organic matters. But, on the other hand, the large amounts of it that are found in the stalks of grain and grass, — to say nothing of the scouring-rush (Equisetum), — continually suggest a doubt whether such plants may not in some way derive advantage from it.

Ritthausen has suggested that silica may possibly do good by clogging in due season the cell walls of the older parts of plants. He urges that, when silica is deposited as a gelatinous or flocculent mass on the walls of cells, the diffusion of the sap must there be hindered, and very much in the same proportion as the amount of the silica, so that finally the movement of sap will cease in the leaves specially affected. But this gradual dying of the lower leaves is helpful for the growth of new leaves and shoots in other parts of the plant, to which the useful matters that were contained in the lower leaves will naturally flow while the latter are dying. In this point of view, slow clogging is essential; for if the lower leaves were to perish suddenly, their constituents could not pass out from them, and would consequently be unable to serve any useful purpose for the rest of the plant. The deposition of too much silica in the earlier stages of growth would be harmful, by causing premature destruction of the leaves, before they had fulfilled their legitimate purposes, so that the normal development of the plant would be impaired.

Recent experiments of Wolff, made by way of water culture and continued through several years, go to show that silica helps the formation of grain. In the case of oats, at least, a larger number of perfect grains were formed in the presence of silica than in its absence.

Other things being equal, vigorous succulent, luxuriant plants usually contain as large a proportion of ash ingredients as those of scantier growth, and they often contain more than the latter. Experiments go to show that grain plants usually contain more potash and lime, and less silica (often less phosphoric acid also), when they are rank and succulent, than when they are stunted, whence the inference that from one and the same soil more ashes will be taken up by a vigorous than by a feeble crop. Weeds are noticeably rich in ashes.

It may be said, in general, that from a soil highly charged with plant-food a crop will take up far more of some kinds of nourishment than it has any use for; but that this excess will not increase the yield of the crop, nor do the plant any good. As regards the grain crops, the excess of ash ingredients thus taken up over and above what is needed for moving the starch and albumen, or what not, is simply heaped up in the straw, and in this fact is found the reason of the high estimation in which straw is held as a manure. If hay is to be sold off a farm, it will be better to sell that mown upon old fields rather than that from newly manured land, where the crop will naturally have surcharged itself with ash ingredients.

Familiar Examples of Movements of Matter in Plants.

Beside the very evident changes which occur when plants are ripening their seeds, there are other familiar appearances which enforce the lesson that each part of a plant has its own particular purpose to perform for the support of the other parts. For example, the great general fact, that one set of organs may take the things necessary for them from another set, where they have been elaborated, is clearly illustrated when a cutting is planted and roots are thrown out from it at the expense of the matter which the cutting contains. In a precisely similar way, one part of a plant may be seen to grow actively, while another part is quiescent, or even dying. Nothing is more common than to see the lower leaves of a plant curl up and drop off at the very time when the upper leaves are in a condition of vigorous growth, and it is now well known that there is an incessant transference of matter from the older to the newer parts of plants.

Development of Roots.

As has been already insisted, most plants in their earliest youth, immediately after the very first leaves have appeared, develop a comparatively large mass of roots before much growth can occur above ground. The course of growth of grain, for example, is first a number of low-lying leaves, while a great complex of roots is in process of formation, and then suddenly the stalk of the plant shoots up all at once almost to mature stature. This peculiar habit of growth may be well seen in winter rye, which is a crop that makes ready in autumn for the very rapid development of leaves and stalks in the next spring.

Probably the roots of most annual plants are completely developed by the time the formation of the fruit has begun. With biennial plants, also, this phenomenon of a great development of roots during the earlier periods of growth is very evident. The common weed, burdock, for example, offers a conspicuous instance of it.

With perennial plants, moreover, the growth of a new suit of roots in the spring of each year precedes any rapid growth above ground. Indeed, Hellriegel, who grew clover two years in succession in glass jars, observed that a new course of life set in every time the plants were mown. First of all, an energetic movement of life was seen below ground, where a multitude of new root fibres were sent out into the earth in all directions, and subsequently a new growth of leaves and stalks appeared; i. e. the growth above ground followed the development of the roots in due course.

In general, the first development of roots and leaves in biennial and perennial plants does not differ especially from that in annuals, but towards the end of summer such plants proceed to store up in their stems or roots a great quantity of nutritive matters which shall serve the next spring for nourishing the first shoots and leaves and rootlets, much in the same way that the matters in a seed nourish the young plant at the time of germination. It has long been known that, in deciduous trees, for example, great quantities of starch and other matters are stored up within the tissues of the stems and roots towards the end of summer and in early autumn. Before the leaves of trees fall in autumn, they have given up to the twigs and stem a large proportion of the starch and albuminoids, as well as the potash, phosphoric acid, and other useful ash ingredients, that were previously contained in them. But the next spring, when returning warmth excites the tree to renewed vigor, the starch which has thus been stored is changed to sugar, or dextrin, or gum, and these substances, together with the other matters that were laid by, serve for the development of new foliage. In evergreen trees there is less need that starch should be stored in the wood, because such trees are constantly covered with foliage, and have no such marked period of rest as the deciduous trees.

Storing of Food for the next Year's Use.

Several familiar crops consist of reservoirs of nutritive matters that have been stored away for the next year's use by biennial plants. Such plants as beets, carrots, turnips, parsnips, salsify, onions, and potatoes, for example, are in this category, and so are cabbages, kohlrabi, and cauliflowers. During the greater part of the summer the leaves of these plants elaborate food, and transfer it to the underground tap-roots or tubers, or to the "heads" of cabbages or the like, which accordingly grow to a large size by the time when cold weather sets in. Next year, if such roots are placed in the earth, they immediately proceed to throw up a flower-stalk, which bears seeds in due course, both the flowers and seeds being nourished for the most part by the matters that were accumulated in the root or stem during the previous year.

So it is with the trees which store up starch, etc., in the winter for the next year's use. Desbarres found in peeled wood from young twigs of Rhus elegans in winter, and in spring after buds had unfolded, the following substances: —

	Winter. %	Spring. %
Dry matter	72.16	66.70
Ashes	1.60	1.23
Starch	17.31	1.57
Albuminoids	9.42	2.25

Besides starch, various other matters are thus stored, notably albuminoids, pectose, fatty oils, and amids, as has been said. In some plants, such as the sugar-cane, sorghum, Indian corn, and beet roots, starch is replaced by cane sugar, and in the onion by a variety of grape sugar. In the roots of other plants, such as the dahlia, and others of the Compositæ, inulin is found instead of starch.

Flowers and Fruit are derived from Leaves.

It is true in general, not only of biennial and perennial plants, but of annuals also, that flowers and fruit derive most of their constituents not immediately from the air or from the soil, but either directly or indirectly from the leaves in which matters taken in from the air or from the soil have been transformed into organized substances.

The importance of having well-developed leaves in order that a crop may succeed, has been illustrated repeatedly in experiments that were made many years ago, in the hope of checking the potato rot. The idea was, that if the potato vines were mown immediately after the fungus (Peronospera) which causes the disease had appeared upon them, the progress of the latter might be checked, and a considerable harvest of tubers still be obtained. There is probably something of truth in this conception in so far as it relates to the saving of tubers that have already grown before the fungus appears, and, were it not for the cost of the operation, it might be well to mow potato vines as soon as the rot fungus is seen upon them.

But it must be remembered that the tubers will practically cease to grow when the vines have been cut off, either by means of a scythe, or through the destructive action of the rot fungus. By removing the leaves, the plants are deprived of the organs in which matters are elaborated for increasing the size and weight of the tubers. The following experiment, by Dietrich, may be taken as a sample of many.

On a potato field that had been planted May 20, he staked out four plots, each containing 150 plants, and he tested and mowed the plots at four different periods, as follows. Ten weeks after planting (i. e. on July 29) 50 plants were dug up on Plot I., and the vines of the other hundred plants were cut off a short distance above the earth. In this case new shoots were speedily thrown up, but they were afterwards attacked by the rot fungus. Twelve weeks after planting (August 16) Plot II., and fourteen weeks after planting (August 30) Plot III., were treated in the same way; but no new shoots came up in either of these cases. Eighteen weeks after planting (September 13), the vines on Plot IV. were found to be dead. Indeed, they had disappeared so completely that there was nothing left to cut; hence the tubers of 50 plants were dug up at that time, while those of the other 100 plants were left in the ground. Up to the 16th of August, the growth of the crop appeared to be excellent; but at that time it became evident that the rot fungus was firmly established upon the plants. At the time of the third mowing, the vines were wellnigh destroyed by the fungus. On the 4th of October the tubers were dug on all the plots and weighed. In the table the results are all stated in terms of 100 plants, merely for the sake of convenience.

100 Plants pulled upon	Yielded lb. of Tubers.	100 Plants mown on	Gave lb. of Tubers in Oct.
29 July	20	29 July	31
16 August	61	16 August	74
30 August	99½	30 August	65
13 September	71	13 September	78

No rotting potatoes were found where the vines had been mown, excepting one quarter of a pound in the case where the vines were mown on July 29. But small quantities (1 or 2 lb.) of the potatoes that had been pulled up were found to be rotten at the time of weighing.

Ten weeks after planting the potatoes, which were of a later variety than is usually grown nowadays, it was observed that no more than half the normal number of tubers had grown, and that these were small, and hardly half as heavy as they should be. The disease was even then at work, and all the subsequent trials were vitiated by the presence of it. It was evident that, as soon as potato vines are attacked by the peronospera fungus, they cease to be able to supply materials for the development of the tubers, and that consequently no harm can then be done by cutting the vines away.

Harvesting of Forage Crops.

From what has been said of the functions of leaves, it follows that a forage crop, like hay, should be cut not very much later than the time of flowering; or, rather, it should be cut before the seeds have made too much progress towards maturity. If grass were left until its seeds had actually ripened, a great part of the albumen, starch, and other materials which have value as fodder, would have gone out of the leaves and stem into the seeds. But the seeds may easily be lost, either by dropping out of the hay, or by passing undigested through the stomachs of the cattle, or by being eaten by mice and weevils. When this country was newer than it is now, it was a constant subject of remark among farmers, that timothy is apt to spring up on wild wood roads where horse dung has been dropped.

In general, it will be best not to mow grass at the moment of flowering, but soon after the seeds have begun to form; that is to say, while the seeds are still soft and watery, for the sum total of nourishment in the plant will then be larger than when the plant was in flower. But, practically, care must be taken not to delay too long, because of the tendency of the seeds to ripen at the expense of the stalk after the harvest; and because of the fact that the lower part of the grass stems begins to deteriorate immediately after the plant has flowered, that is to say, as soon as the seed begins to grow at the expense of the matters in the stem.

The oat plant affords a striking instance of the liability of hay to undergo this kind of deterioration. Cut soon after flowering, the entire plant is greedily eaten by cattle, and it constitutes an admirable kind of forage; but after the grain has ripened, oat straw is not much better than any other kind of straw.

There is no need to insist that the ripe oat crop, that is to say a mixture of ripe oats and dead straw, would usually be a less advantageous kind of fodder than oat hay cut at such a stage of growth that pretty much all of the nutriment of the ripe crop would be evenly distributed in every part of it. It is true enough that by passing the ripe straw through a hay-cutter together with the oat grain, and steaming the mixture, an excellent fodder could be prepared; but it would not be much better than the oat hay, and it would be more costly.

It should be clearly understood, however, that in no case, either from the ripest straw or from dead autumn leaves, have the nutritive and fertilizing constituents passed completely out from the older parts of the plant, for the walls of their cells, or a part of these walls at least, must necessarily remain behind in any event, and a small part of the contents of the cells must remain also.

Harvesting of Grain.

With regard to the phenomena which determine the times of harvesting grain crops, it is a matter of familiar observation that the standing crop ceases to grow soon after the ears have fairly formed. It is evident enough that from this time forward the grain ripens at the expense of the leaves and stalks. Hence the common custom of farmers to cut grain before it is fully ripe, and to leave it to ripen in sheaves and stooks, in order to avoid loss by shaking. After the heads have fairly formed, it is little matter whether the plants remain connected with their roots or not. In either event, it can be seen that the stalks gradually dry up and change to straw, from below upwards.

These changes are similar in kind, though less emphatic in degree, than those witnessed in the experiment of Boussingault, where oat plants, taken from a field when in blossom, and thereafter kept in distilled water, ripened a number of seeds of good quality; or in the experiment of Knop, who found that a maize plant, grown by way of water culture, had taken up at the time of flowering enough matter to enable it to perfect its fruit. The plant in question produced and ripened a perfect ear of corn, although after the time of flowering it received no nourishment whatever other than what it could get from atmospheric air and pure distilled water. The details of the changes which plants undergo in ripening have been carefully studied by several chemists, particularly with regard to the oat plant, under which head they will be more fully considered.

Dead-ripe Seeds the best for Sowing.

The significance of after-ripening for the formation of perfect seeds has been studied by Hellriegel in connection with the question as to the influence of ripeness on the germinative power of seeds. He selected a number of rye plants, from a good field of this grain, at five different periods of ripeness. 1st. On June 26, when both grain and straw were still completely green, and the seeds very small and watery. They yielded a clear liquid when pressed. 2d. On July 3, when the straw was still green, though the seeds were large. They yielded a milky juice. 3d. On July 10, when the straw had begun to be yellow, and the seeds were full of starch, though still green and very soft. 4th. On July 18, when the straw was yellow and rather dry, and the seeds hard and no longer juicy (yellow-ripe). 5th. On July 30, when both straw and grain were dry, and the latter much inclined to shake out of the ears (dead ripe).

Each of these five collections was divided into four portions, as follows: 1st. A quantity of the grain was completely removed from the plant at the moment of collection, so that the seeds could thenceforth get nothing from the plant. 2d. A number of ears were cut off and tied up in bundles. Here a small amount of after-ripening was possible, at the expense of the chaff. 3d. A number of stalks were cut off several inches above the earth, to imitate the ordinary process of reaping, and then tied in sheaves. Here after-ripening could occur, as in ordinary field practice. 4th. A number of plants were dug up so as to leave as many as possible of the roots attached to the stalks, and the plants were then placed with their roots in distilled water; the idea being to facilitate, in so far, the process of after-ripening. At the end of September all the seeds were removed from the plants, and parcels of them were sown in pots and in the field at the beginning of October. Each of the parcels sown in pots contained 100 seeds, and those sown in the field contained 60 seeds. Two kinds of soil were chosen, one a rich garden earth, and the other a poor sandy loam. So that each of the trials was duplicated. The seeds of the first collection were diminutively small, and even those of the third collection were much shrivelled. The following table gives the absolute weight in milligrams of 100 of the air-dried seeds as collected at the several stages of ripeness above described.

	I.	II.	III.	IV.	V.
Seeds removed immediately from ears .	1043	1466	1837	2029	2223
Seeds left in the ears	1058	1483	1851	2030	2225
Seeds left attached to the straw . . .	1131	1493	1862	2030	2228
Seeds left on plants whose roots were placed in water	1379	1544	2022	2107	2233

Whence it appears that the seeds of the first collection had acquired less than half, and those of the second collection hardly two thirds, their normal development.

The comparative heaviness of the several parcels is shown by the following table, which gives the specific gravities of the air-dried seeds, at the several stages of ripeness, as before.

	I.	II.	III.	IV.	V.
Seeds removed immediately from ears .	1.165	1.260	1.260	1.280	1.290
Seeds left in the ears	1.165	1.270	1.280	1.290	1.290
Seeds left attached to the straw . . .	1.165	1.260	1.270	1.290	1.290
Seeds left on plants whose roots were in water	1.230	1.270	1.280	1.290	1.300

The following tabular statements give the average percentage of seeds that germinated and grew when sown in jars of earth.

A. Seeds that were removed immediately from the ears : —

I.	II.	III.	IV.	V.
4⅓	5	9½	36	84

It appears clearly that in the earlier stages of their development the seeds have very little germinative power; that this power increases with the development, and is at its best when the seeds are fully ripe. Indeed, Hellriegel expresses a doubt whether it can justly be said that seeds so immature as those of his first two periods are capable of germination; for since the seeds in an ear of grain do not all develop at precisely the same rate, it is possible that a few precocious individuals may have attained a degree of ripeness not really proper to those periods. It is remarkable that even the seeds of the 4th collection did not germinate freely, although they were tolerably hard and dry when taken from the ears. The young plants from the over-ripe seeds were decidedly the strongest and most vigorous, the others being smaller and feebler very much in proportion as the seeds from which they grew had been gathered earlier.

The results of the trials with seeds sown in the open field were similar to the foregoing; the less ripe the seeds, the fewer of them germinated, and the weaker were the young plants. On the sandy soil, these differences persisted throughout the entire life of the plant, but in the rich garden soil the weak plants soon grew strong, and were equal to the best before they had ripened. As Hellriegel has shown in another connection, the hurtful influence of light seeds may speedily be overcome in a fertile soil where all the conditions are favorable for growth, while on poor or dry land a crop may never recover when thus crippled at the start.

B. Of seeds that were left attached to the straw until just before sowing, and so subjected to after-ripening, there germinated,

I.	II.	III.	IV	V.
77½	77½	78½	38½	88

It is noteworthy what an enormous influence the after-ripening had upon the germination of seeds from the 1st and 2d collections. But it was remarked that as regards the vigor of the young plants the influence of the after-ripening was less pronounced.

C. Of seeds that were left in the ears merely, there germinated,

I.	II.	III.	IV.	V.
81	72	82	84	84½

Even here, where the after-ripening was due merely to matters that could pass out of the chaff into the seeds, the germinative power was enormously increased, though the young plants were very feeble.

D. The seeds left on plants whose roots were put in water germinated as follows: —

I.	II.	III.	IV.	V.
61	62½	87	91	84½

These results were disappointing, because better things had been expected; but in view of the rough-manner in which the plants were dug up (with a spade), it is easy to believe that their roots were injured, and that the plants were in no fit condition to nourish their seeds normally.

The following experiment may serve to illustrate the rapidity with which after-ripening occurs. A quantity of rye was mown before complete ripeness; one quarter of it was deprived at once of its seeds, and the rest kept in a cool, shady place, where the plants could ripen off without spoiling, or drying too quickly. After 8 days the second quarter was threshed, after 27 days the third quarter, and after 50 days the fourth. One thousand kernels of this rye dried at 212° F. weighed in grams: —

		Gain in Per Cent.
Taken from the ear immediately on harvesting . . .	19.890	. . . .
Ditto, after 8 days	22.100	11.1
Ditto, after 27 days	22.240	11.8
Ditto, after 50 days	22.050	10.9

That is to say, 8 days, and to all appearance less, were sufficient to complete the process of after-ripening.

It is evident from Hellriegel's experiments that, for use as seed-grain, dead-ripe seeds must be in all cases the best and the surest, and that, the less ripe the seed, so much the feebler will be its germinative power and the initial productive power of the young plant. Practical illustration of these propositions is given constantly by those over-ripe kernels which shake out upon the fields when grain is harvested. When timely showers occur, such self-planted grain will sometimes germinate and grow with a vigor which is surprising.

Imperfect Seeds are specially ill-adapted for Poor Land.

On poor land, two marked disadvantages, due to imperfect seeds, manifest themselves; viz. fewer plants are developed than there would be by good seed, and these weak plants remain feeble all their lives. Whereas on good soils, as has been said, the chief trouble from poor seed is that comparatively few plants are developed. What plants there are soon overcome their first weakness, and finally attain to a robust development. Thus Hellriegel found, as the average of his four series of experiments, that each single rye plant grown on sandy loam yielded the following amounts in grams according as the seeds had been collected at the stated periods of development: —

	Grain.	Straw and Chaff.	Total Crop.
No. I.	0.127	0.770	0.897
No. II.	0.445	1.266	1.711
No. III.	1.062	2.697	3.759
No. IV.	1.181	2.886	4.047
No. V.	1.075	2.824	3.899

But when grown in garden earth, each single plant yielded on the average of the four series of experiments: —

No. I.	4.693	9.241	13.934
No. II.	5.116	10.735	15.851
No. III.	5.553	10.553	16.106
No. IV.	5.436	10.926	16.362
No. V.	5.725	11.211	16.936

Crops need to be fed when Young.

There is still another point of view from which to regard the process of ripening. Inasmuch as every plant has to form roots, leaves, and stem before the fruit can appear, i. e. organs which collect and store up the materials from which the fruit is formed, it follows that, in case a plant has not been able to collect a sufficient quantity of these fruit-producing constituents by the time of flowering, it cannot by any possibility bear abundant fruit. Hence the importance of supplying to seed-crops from the first moment of their growth proper quantities of all the kinds of food that are necessary to form grain as well as leaves. Knop's maize plant, for instance, would not have ripened seed as it did unless it had been well fed when young.

With forage crops the case is somewhat different. There would be no great harm in forcing them to bear luxuriant leaves by means of nitrogenized manures, provided always that the growth is not so rank that the plants will lodge. It would be mere folly, however, to attempt to force a grain crop in this way, unless the young plants had access to an abundance of phosphoric acid, and all the other ash ingredients necessary for the formation of grain, as well as to nitrogen, and unless the conditions were favorable for the consumption of the ash ingredients by the plants.

The same reasoning that teaches the necessity of the early harvesting of forage crops applies of course to green crops that are to be turned under as manure. They should be ploughed under when in flower, or even just before flowering, for at that time they are richest in easily decomposable organic matters, and contain nearly all the ash ingredients they are capable of taking. It is usually important, moreover, in green manuring, to save as much time as possible in order to get in another crop, and to avoid the formation of seeds, whether those of the crop itself or of the weeds that grow with it.

Large Beets and Turnips less Nutritious than Small.

In respect to root crops, a consideration of general interest is whether large roots or small roots are most nutritious. It was noticed long ago by the German farmers, that, when they manured mangolds with night-soil, they got enormous roots indeed, but very watery roots. And careful experiments have confirmed this observation; so that, as a general rule, it may be said, the larger the root, the larger the proportion of water contained in it, as compared with the amount of solid matter. But, on the other hand, there can be no doubt that it is good husbandry to grow large roots when possible, since the advantages as regards labor and supervision are greatly in their favor.

As for the greater feeding value of small roots, it was noticed at the close of the last century by Young, that in some parts of England the butchers preferred and would give more money for turnips that had never been hoed, and had consequently grown no larger than a double fist, to those which had been cultivated with the greatest care, and were as large as a peck measure. Young ridiculed the idea, and from the farmer's point of view it is absurd; but for the butcher, who buys the turnips by weight, merely as so much cattle food, and who has no profit in cultivating them, the small ones are doubtless best.

With regard to the comparative power of various crops to exhaust land, enough has been said perhaps already under the head of Rotation.

CHAPTER XVIII.

BARLEY.

Barley may well be studied as the first example of a special crop, because it is the most widely distributed of the grains. It has been longer cultivated, perhaps, and more generally cultivated, than any other. The growth of the barley plant has been very carefully investigated withal from the scientific point of view. Barley grows very far to the north, even in Lapland and Iceland. Good crops are got constantly in some localities as high as latitude 70°. It has the great merit that its term of growth is short. And this statement is particularly true of high latitudes, at least as regards sheltered sunny situations not too high above the sea level.

In some Swedish localities barley is said sometimes to ripen in the course of six weeks, and not infrequently in seven or eight weeks. So too in some Norwegian valleys, barley is reaped in favorable years 8 or 9 weeks after the seeds are sown, and it is possible to get two crops in a summer. Indeed, there is a farm in Thelemarken called Triset, which owes its name to the fact that one year three successive barley crops were reaped upon it. In those regions the stalks are often seen to grow two or three inches in a day. Ordinarily, however, the term of growth of the barley crop is some 80 or 90 days, say 13 weeks. Although grown far to the north, barley is not so well able as rye or wheat to live through the winter. Even in New England it is grown as a summer crop, though in countries where the winters are milder varieties of winter barley are sometimes cultivated.

Mention has already been made of the influence of continuous light in hastening the growth of barley in high northern latitudes, and of the remarkable circumstance that the character there impressed upon the crop by its exposure to light through many generations may be retained for a time when the seed is carried to more southern localities. In one experiment, barley that bore ripe grain at Alten (70° N.) 67 days after it was sown, required only 67 days to ripen at Breslau in Germany (51° N.); and an instance is reported where some of the Alten barley sown at Christiania (60° N.) ripened in 55 days, the crop having been somewhat forced, as was supposed, by the warmer climate of Christiania.

Barley has a wide Range.

Barley is still cultivated more frequently in Sweden and Norway than any other grain. As a matter of history, it has been longer cultivated there than any other cereal. It was grown there even earlier than rye. Indeed, the name "corn" has been applied exclusively to barley by the Northmen from very early times. In Iceland, barley was grown from the time the island was colonized, in 870, till the middle of the fourteenth century, or even as late as the year 1400. After that time, however, the Icelanders appear to have imported their supplies of grain, and not to have grown barley in any systematic way; though in the last century efforts were made to have the old custom revived, and again quite recently. In 1883, barley was reaped at Reykjavik in Iceland 98 days after the seed was sown. The chief difficulty in these northern countries is from severe night frosts when the barley plants are young. Such frosts are often very destructive.

In the year 1880 some 2,660,000 acres of barley were grown in England and Scotland, against 3,000,000 acres of wheat and 49,000 acres of rye.

Barley grows far to the south also as well as at the north, and it is much used for feeding horses in some southern countries. Indeed, it habitually yields two crops each year on the same soil in hot climates. In Sicily the barley sown in autumn ripens in May, and that sown in May ripens before the autumn. In temperate climates barley is much less important nowadays even than rye, when considered merely as a bread crop, but large quantities of it are still grown for the purpose of making beer and malt, and not a little barley is used directly as fodder.

Why Barley is used for Beer.

The reason why barley is used for making beer in preference to the other grains, such as rye, wheat, or maize, is that barley malt contains a larger proportion of certain unorganized ferments, such as "diastase" and "maltin," than malt that has been made from either of the other kinds of grain. In all kinds of starchy seeds the starch changes to sugar and dextrin at the moment of germination, through the action of the albuminous matters of the seed; or, rather, the albuminous matters themselves undergo such changes when the seed germinates that some parts of them act as ferments as regards the starch, which is thereby changed first to dextrin and then to sugar.

In germinating barley, in particular, these altered albuminoids are found in special abundance, and of peculiar efficiency for changing starch to sugar. It is from barley malt that diastase and maltin may be most readily obtained, and it is because of their being specially abundant in such malt that barley is grown for the making of it. There is, indeed, no more than one part of diastase in some five hundred parts of barley malt, but this quantity is ample for all practical purposes, since one part of diastase is capable of changing one or two thousand parts of starch to sugar, provided it is made to act at a temperature of 149° to 158° F.

Maltin is said to be even more active than diastase, being capable of converting from one- to two-hundred thousand parts of starch into a soluble condition. Barley malt may contain as much as one per cent of it.

Malting a Process of Germination.

After starch has once been changed to sugar, it is an easy matter to convert the sugar into alcohol by fermenting it with ordinary yeast. Practically, the process of malting barley, or any other kind of grain, is only an artificial method of germination. The grain is steeped in water to make it soft, then drained and thrown into heaps. After a while these heaps become hot and dry, and in the course of a few days each grain "sprouts," i. e. it throws out rootlets. The heaps are then spread to prevent the grain from becoming too hot, and when the rootlets have grown to a length about equal to that of the grain the progress of the germination is suddenly arrested by drying the grain, either in the air, or, more commonly, in a kiln. After the roots have been rubbed off from the grain thus dried, the latter is called malt. The matter rubbed off is known as malt-sprouts or malt-combs, and is used for feeding cattle. When malt, or a mixture of malt and fresh grain, is crushed and soaked in warm water for a few hours, the whole of the starch in the mixture changes to sugar and dextrin, as was said.

Neither diastase nor maltin is peculiar to barley. They are found in other germinating grains; small amounts of diastase have been found even in potatoes. Any kind of grain may be malted in the same way that barley is. But practically barley is found to be better than the other grains for this purpose, and barley malt is commonly used for preparing other kinds of grain for distillation. Enormous quantities of maize, and rye, and rice, and wheat even, as well as potatoes, and occasionally Jerusalem artichokes, are used every day for making beer and whiskey; but they are, comparatively speaking, seldom malted. Instead of that, the grains or the potatoes are mixed with barley malt for the so-called mashing process, during which their starch is changed to sugar. Then the sugar is fermented, and, if whiskey is to be made, the fermented liquor is distilled to separate the alcoholic liquid from the refuse slop, which is used as cattle food.

Barley a delicate Crop.

Curiously enough, in spite of the fact that barley has so wide a range, and is so hardy that at the extreme north it is grown freely where the soil never melts to a depth greater than a few inches, it is rather a tender plant, both in this country and in England. In the region about Boston, a cold easterly rain-storm descending in the spring upon a barley field where the young plants are just starting will give the crop a serious check, almost as if the plants had been frozen. Too much rain in northern countries is fatal to it. Thus barley is said to ripen at Alten at 70° north latitude, where there are 21 rainy days during its term of growth, while at Reykinvig at 64° 45′, where there are 51 rainy days, it can no longer be grown. It is said to prefer a warm, dry climate, with occasional light showers. Heavy rains are apt to injure it in all countries, especially when they fall soon after sowing, or while the plants are in blossom or ripening.

From experiments made at Dahme, in Germany, it appears that, although barley succeeds best when the temperature of the soil is kept at 77° F., while rye does best at 68°, it is none the less true that barley can be grown as far to the north as rye, or even farther, because it grows faster. Barley can germinate even at the temperature of melting ice. According to Sachs, the lowest temperature at which barley plants grow is 41°, and the highest 100° F.

Best Temperature for growing Barley.

Hellriegel finds by experiment, that, when all the other conditions requisite for successful growth have been provided for, a mean daily temperature of 61° F. (as taken in the air and in the shade) is most favorable for the growth of barley, i. e. when the whole term of growth of the crop is considered. During the first half of its life, when the leaves and stem are growing, a temperature of 59° is best; while for the second half of the plant's life, when the ears and grain are in process of development, the mean daily temperature had better be 63 or 64°. For growing a perfect crop, the mean temperature at noon should not exceed 70° in the shade during the entire term of growth; nor 68° during the first period of growth; nor 73° during the second period. Temperatures higher than 77° measured in the shade during the period of leaf development, or than 82° during the period of seed development, were found to have a decidedly bad influence on the amount of crop produced.

Barley a Fastidious Crop.

It is often said of barley, that few crops are more strongly affected by food. Few crops respond more quickly to a generous diet, or languish more decidedly when food is lacking. Farmers hold that the best soil for barley is a light, rich, friable loam; but that it will do well on clays also, provided they have been thoroughly worked, and made fine and mellow.

Practical men are firmly of the opinion that heavy land, which has not been well tilled, is unfit for barley. They maintain that, more than most other crops, barley delights in a free, open soil, that is neither too wet nor too stiff; all of which goes to show that the plant is somewhat delicate or fastidious, as compared with oats or buckwheat, or with maize even, or the other grains. Formerly, it was taught by English writers that barley should be grown in those districts where the soil is light, rather than in regions where the soil is heavy; and it was thought that, although the plant is well suited by calcareous soils, it will not prosper as a rule on clays, nor upon sandy soils. But it has happened in England, as a consequence of the adoption of tile drainage and steam cultivation, which permit the clays to be worked much better than could be done formerly, and at appropriate seasons withal, that the successful cultivation of barley has been widely extended. Of late years, a great deal of barley of excellent quality has been grown in the clay-land districts of England after wheat. The wheat stubble is steam-ploughed in the autumn, when dry; and in the early spring, when the land is dry, it is harrowed, or very lightly ploughed, for the reception of the seed.

It was a maxim of the old English farmers, that there is small use in applying farmyard manure to a crop which is to remain on the land so short a time as barley does; their argument being that the land must be prepared for the barley beforehand by manuring some preceding crop. Not infrequently, however, in the light land districts they grew barley after turnips. The turnips were eaten by sheep in the fields, and the land was ploughed lightly soon after the sheep were taken off, in order to cover their droppings. Sometimes the barley was sown on this first furrow; but, in case the ploughing were done early in the season, the land was cultivated or harrowed again before seeding, it being considered all important to have a well-pulverized seed-bed. This line of argument would lead naturally to the use of quick-acting fertilizers, such, for example, as Peruvian guano, especially that which has been treated with sulphuric acid. As a matter of fact, the farmers of the beer region in the North of France — in the vicinity of Lille, for instance — are accustomed to apply liquid manure to their barley, or, in default of that, to use very well rotted dung.

These views, both as regards soil and manure, appear to be reasonable. The roots of the barley plant grow rapidly, they are feeble and short-lived, and are ill adapted to surmount obstacles such as would be presented by a compact soil, or to utilize fertilizing materials which are not ready and waiting to be taken in.

On the other hand, it is important not to use such manures, or such quantities of manure, as would tend to make the crop run to leaf rather than to bear seeds. In some parts of Germany, where large quantities of barley are grown in conjunction with sugar beets, two crops of barley are often taken after one of beets. It is said that the second barley crop usually succeeds well, and that the grain is of excellent quality and appearance. On the heavy English soils just now mentioned, the barley is dressed liberally with artificial fertilizers, viz. with 2 or 3 cwt. of superphosphate applied before seeding, and from ½ to 1 cwt. of nitrate of soda.

Some of the experiments of Lawes and Gilbert bear upon this point. For many years these investigators have continually grown crops of barley (as well as of wheat) upon the same fields, and some of their results are set forth in the following table. The soil of their fields is "a somewhat heavy loam, with a subsoil of raw, yellowish red clay, but resting in its turn upon chalk, which provides good natural drainage." The crops harvested were as follows: —

Manure to the Acre.	1st Year. Grain. bush.	1st Year. Straw. cwt.	20th Year. Grain. bush.	20th Year. Straw. cwt.	Average of 20 Years. Grain. bush.	Average of 20 Years. Straw. cwt.
14 tons of farmyard manure	33	18½	54¼	37⅛	48¼	28¼
No manure	27¼	16⅝	16¾	11	20	11¾
Mixed minerals[1]	32¾	19½	25	14	27½	14⅜
200 lb. ammonium salts[2]	36⅞	22⅞	36⅜	23⅛	32½	18½
Mixed minerals and 200 lb. ammonium salts	40¾	27⅞	46½	32½	46¼	28½
Minerals and 400 lb. ammonium salts[3]	45⅛	28⅜	46	32⅝	49¾	32⅜
Minerals and 2,000 lb. rape-cake[4]	38	24⅛	47½	32	47⅜	29½

Dead-ripe Barley best for Malting.

It is said that, when barley is to be used for making beer, it must not be harvested before it is dead ripe. The rule is to wait until the ears droop, and have lost their reddish color. The argument in this case is, that, for the success of the malting process, it is important to have the grain all of one stage of ripeness, so that it shall germinate simultaneously; and, in order to this result, each and every kernel of the grain must be perfectly ripe. But when grown for use on the farm, it may be said of barley, even more strongly perhaps than of other grains, that it should be cut down while the seed is still not very hard, and the straw not absolutely dry. The sheaves are then left for some time in the field, in order that the grain may finish taking nutriment out of the straw, and so ripen; for if the crop is left standing too long, much grain will inevitably shake out from the ears and be lost during the process of reaping. On the other hand, if sheaves of barley, or of any other grain, were to be housed, or put in a stack, immediately after reaping, fermentation and decay would set in, the process of after-ripening would be interrupted, and the crop be spoiled.

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[1] The mixed minerals consisted per acre and per annum of 300 lb. of sulphate of potash during the first 6 years, and 200 lb. thereafter; 200 lb. of sulphate of soda during the first 6 years, and 100 lb. afterwards; 100 lb. of sulphate of magnesia; and 200 lb. of bone-ash treated with 150 lb. of sulphuric acid of 1.7 sp. gr.

[2] The ammonium salts consisted of an equal mixture of the sulphate and the chloride.

[3] After the 6th year, and during the next 10 years, 200 lb. of the ammonium salts; and subsequently 275 lb. of nitrate of soda were used.

[4] After the 6th year, 1,000 lb. of rape-cake were used each year, instead of 2,000.

In some countries it was customary formerly to mow barley in the spring in case it threatened to be over luxuriant, or to have it eaten down by sheep. In this way animals may be supplied with very nutritious fodder. Mowing was esteemed to be better than pasturing, since it was easy to cut off only the rankest plants with the scythe, and so to bring the crop to a condition of comparative evenness. So, too, in autumn, excellent fall feed for soiling cattle can be got by sowing fresh barley, such as rattles out from the sheaves immediately after they have been harvested.

Hellriegel's Perfect Barley Plants.

A great number of highly interesting experiments on the growth of barley[1] have been made by Hellriegel at Dahme, in Germany. He propounded to himself squarely the question, How much barley could be grown on an acre of land provided all the conditions were the most favorable that can be conceived? That is to say, what would be, theoretically speaking, the maximum harvest? As conditions essential to perfection Hellriegel admits that the plants must have a certain volume of porous soil, which shall afford the necessary space for the development of the roots, a sufficient supply of moisture, definite quantities of assimilable food, both in the air and in the soil, as well as specific amounts of light, heat, and time. Strictly speaking, each one of these conditions is as important as any other. Either of them may exert a decisive influence upon the quantity of the crop; and it is only when each and all of the conditions are present in proper quantity or force, i. e. when they make themselves felt in just proportion, that the best possible or really normal plant can be obtained.

It will be seen at once, that, though theoretically of equal weight, some of these conditions are practically much more easily controlled than others. It is a comparatively easy matter, for example, to supply in field practice as much phosphoric acid, nitrogen, or potash as may be needed by a maximum crop, though in many instances it would be very difficult to provide enough water for the purpose. Over heat and light, moreover, the farmer has little or no control.

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[1] The small four-rowed variety (Hordeum vulgare).

Hellriegel assumed that, when all the conditions necessary for a perfect crop have been found out, it will be possible to alter the character of the crop at will, or the quantity of the crop, by changing certain of the conditions. Acting on these ideas, he has succeeded in growing perfectly healthy plants, much larger and more perfect than are ever found in the fields; and, within certain limits, he has been able to control pretty much as he saw fit the influences exerted by light, heat, food, and the other conditions which are necessary to the life of plants. That is to say, by varying the conditions, he was able to produce at will plants of determined size and weight, and to obtain constantly the same results under like conditions.

But this term "like conditions" requires for its fulfilment that the seed-grains shall be of identically the same absolute weight, and of like specific gravity; that they shall be buried to an equal depth, at one and the same time; that they shall have equal quantities of earth, and that the pots shall be placed in common relations with sun and air; that each pot shall be kept equally moist with the rest, and receive the same amount of food, and the same protection from all disturbing influences.

In order to control the matters of light and air, Hellriegel had the pots set upon a sort of wagon, running on a railway, which could be drawn out of or into a glass house at will, according as the weather required. Most of these experiments, which were continued for many years, were made in large glass jars filled with pure quartz sand, to which the necessary nourishment was applied in the form of soluble chemical substances. For example, in order to answer the question, What chemical substances, and what quantity of each, must be present in the soil or the air in order to support the largest possible crop of barley? several distinct series of trials were established by mixing with the sand chemical substances in different proportions, and in each of these series one of the essential elements of plant food was supplied at ten or twelve different rates, ranging from nothing (i. e. 0) at one end of the series up to a very large quantity at the other end, — a quantity so large, namely, that it would surely be in excess of what the plant needed. Thus, in seeking to determine how much potash is required by the barley plant in order that it may be perfect, when the other conditions necessary to the prosperity of the plant are fulfilled, Hellriegel obtained the results given in the following table.

No. of Pot.	Lb. Potash in a Million lb. of Earth.	Weight of Crop.		
		Straw and Chaff.	Grain.	Total.
1	0	0.798	...	...
2	6	3.869	2.933	6.802
3	12	5.740	4.695	10.435
4	24	6.859	7.851	14.710
5	47	8.195	9.578	17.773
6	71	9.327	10.097	19.424
7	94	8.693	9.083	17.776
8	141	8.764	8.529	17.293
9	282	8.916	8.962	17.878

Each of the pots was abundantly supplied with lime, magnesia, soda, iron, silica, nitric acid, sulphuric acid, phosphoric acid, and chlorine; and the results seem to show that between fifty and seventy pounds of potash to a million pounds of earth are necessary for the perfect barley crop. But from analyses of the ashes of the crops obtained as above, Hellriegel concluded that 47 lb. of potash to the million pounds of earth are sufficient, or rather that the necessary quantity lies somewhere between 24 and 47. The reasons for this conclusion will appear from the following table, which gives the per cents of potash in the dry crop. There were found the following numbers of pounds of potash in 100 pounds of the dry crop:—

No. of Pot.	Straw and Chaff.	Grain.
2	0.459	0.175
3	0.371	0.181
4	0.425	0.354
5	0.990	0.375
6	1.791	Lost.
7	2.680	0.497
8	4.068	Lost.
9	6.428	0.669

The proportion of potash in the grain, it will be observed, remains tolerably constant after No. 4. In case the soil contained an excess of potash, some of it did indeed accumulate in the straw, but it did not increase the yield of grain, nor did the grain willingly take in any excess of potash over and above what may be called the necessary quantity.

Even if nothing were known as to the function of potash in the economy of the plant, it would still be manifest from the results of these experiments that potash has some definite work to perform, and that there is no use in sending two pounds of it to do one pound's work. Hellriegel concludes that, for the production of every 1,000 lb. of dry straw and chaff, the barley plant must have at the very least (taking the results of pot No. 4) 5 lb. of potash, and for every 1,000 lb. of grain 3.8 lb. of potash.

Crudeness of Field Practice.

It will be interesting to compare the foregoing ideal with the results of ordinary farm practice, and to observe how far removed we still are from perfection. If it be assumed that the average yield of barley in Massachusetts is 25 bushels to the acre, and that a bushel of this grain weighs 48 lb., there would be 1,200 lb. of grain, needing 4½ lb. of potash; and if the straw of the Massachusetts crop weighed 2,400 lb. to the acre, that would need 12 lb. of potash, or altogether the crop would need 16½ lb. But actually and practically no one would deem it amiss to apply 100 lb. of potash to the acre of land. Eight cords of cow manure might contain more than 200 lb. of potash. This calculation, taken in connection with the fact that the small proportion of potash above mentioned is sufficient to produce a larger crop than was ever harvested in field practice, teaches an emphatic lesson with regard to the manuring of land. It teaches that efforts should be directed towards supplying the soil with small quantities of soluble, diffusible, and easily assimilable fertilizers, instead of heaping upon it great masses of comparatively inert materials.

In the jars of soil which contained less potash than the maximum crop required, Hellriegel observed that the plants were less and less luxuriant, and finally short and stunted. The diminution in size was visibly nearly proportionate to the lack of potash.

Experiments made in the same way with varying quantities of phosphoric acid, or lime, or magnesia gave results which were strictly comparable with those obtained with potash. And, as has been said already, it was proved by means of analogous experiments that the carbonic acid of the air is sufficient for the production of a maximum crop of barley. There was no advantage gained on giving the plants more carbonic acid than the air naturally afforded them.

In the same way, it was proved that the ammonia and nitrates of the air are wholly insufficient for the growth of even a tolerable crop. Thus, in pots that contained all the ash ingredients in abundance, but no nitrogen, the harvest was 0.184 grm. of straw on watering with distilled water, and 0.200 grm. on watering with rain-water, while in similar soil to which a nitrogenous fertilizer was added at the rate of 84 lb. nitrogen to the million pounds of earth, the harvest was : —

Grain.	Straw and Chaff.	Total.
9.083	8.693	17.776

Importance of Light for Growth.

The influence of different amounts of light was tested by growing the crops of barley in free air, and at the front and the back of a glass house. Only the crop obtained in free air was perfect. That at the front of the house was below par, and the one from the back of the house, where there was no direct sunlight, but only diffused light, was very poor. The dry weight of the three crops was as 7 : 3 : 1 (very nearly). All the conditions other than the amount of light being at their best, the harvests were as follows : —

				Weight of Dry Matter in Milligrams.		
	Ears.	Barren Stalks.	No. of Seeds.	Grain.	Straw and Chaff.	Total Crop.
A. Barley grown in free outer air : —						
	17	10	285	10,102	11,436	21,538
	12	8	312	11,188	10,991	22,179
Mean,	15	9	299	10,645	11,214	21,859
B. Grown in front part of glass house in direct light : —						
	11	4	123	2,861	6,716	9,577
	11	3	143	3,265	6,323	9,588
Mean,	11	4	133	3,063	6,520	9,583
C.[1] Grown at back of glass house in diffused light : —						
	0	16	0	....	3,396	3,396
	0	20	0	....	2,594	2,594
Mean,	0	18	0	....	2,995	2,995

So, too, when the plants were somewhat shaded by being covered with glass that was slightly colored, or when they were partially screened with paper shades that daily cut off most of the light from the lower portions of their stems, the amount of crop harvested was invariably lessened.

Hellriegel calls attention to the fact, that the plants in the midst of a grain-field are much less favorably situated as regards light than were the plants of his normal experiments. Each of his plants had constant access to all the light that shone during the entire term of their growth. But in the field the plants are necessarily a good deal shaded by their fellows, except in earliest youth when they are not large enough to interfere with one another, and in maturest age when their leaves have perished. He urges that this point has important bearings upon a number of practical questions, such as, How thick should a grain crop stand? How thickly should meslin be sown? How wide should the distance between the drills be made in sowing one or another crop? and, In what directions should the rows of plants be made to run? For the amount of light that falls upon a field, and the best possible utilization of this light are prime factors for the success of a crop.

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[1] The plants in C were spindling, thin, and soft.

In view of the evidence here presented, there can hardly be a doubt that some part of the detestation in which weeds, as well as trees, growing among crops, are held by practical men, must be credited to the shade they cast. On the other hand, it is not impossible that the unlikeness of the two kinds of plants in a crop of meslin may hinder them from interfering with one another to the same extent as might be the case if either one of the plants stood by itself as thickly.

The Year's Rainfall not enough for a Perfect Barley Crop.

Curiously enough, it was shown, not only for barley, but for wheat, oats, and rye also, that the amount of water which naturally falls at Dahme in the form of rain and dew and snow is insufficient for the production of maximum crops, even if it be supposed that this water could all be stored until it was needed, and then be distributed evenly and in the most advantageous way during the growing season.

Experiments upon the importance of water were made in a sand that was capable of holding 25% of water. It appeared that the barley plants could not grow, no matter how well they were supplied with other kinds of food, unless there was present in the soil from 3 to 5% of water. When the soil contained no more water than 2½%, i. e. no more than would amount to 10% of all the water it could hold in its pores, germinated seeds would not grow at all, though curiously enough they remained alive during six weeks, and then grew well enough on being watered. It was only when the proportion of water in the sand fell below 2½% that the plants wilted; but in order that they should grow, more than 5% of water was necessary.

When water was supplied in quantities ranging from 5 to 20% of the soil, or in other words from 10 to 80% of the maximum quantity which could be held by the sand, it soon appeared that the size of the plants was very nearly proportional to the amount of water they received, and, as time went on, the difference between the well-watered and the thirsty plants became more and more clearly marked. Where there was no more water than amounted to 20% of the sand's capacity, the young plants were slow to start, being some 2 to 5 days later than those which got more water, and it was evident that the plants which got no more water than amounted to from 10 to 20% of what the sand could hold were inadequately supplied. In times of specially hot weather, moreover, all the plants that had less water than amounted to 20% the soil's capacity suffered extremely.

As will be seen from the table which follows, the best results were obtained when the soil was kept pretty thoroughly moistened, but not actually saturated with water. Eighty per cent, or more than 80%, of the soil's water-holding capacity was detrimental; the best conditions being at 50 to 60%.

It was noticed that the well-watered plants were not only larger than the others, and of a bright green color, but that they seemed as if built upon a larger scale, with larger and thicker leaves and branches. As for the color of the plants which were inadequately watered, it was a deep sap-green, similar to that shown by plants that have been fed with an excess of nitrogen; but the general appearance of the plants was, comparatively speaking, stiff and contracted, and it was evident that plants which are forced to grow in a soil which constantly contains less water than the plants would like may adapt themselves in a measure to the situation; their organs become contracted, and their transpiratory surfaces circumscribed. It is to be supposed also, that, whenever there is a lack of moisture in the soil, the contents of the cells are less fluid and less inclined to give up water for transpiration.

It was found, on microscopic examination, that the well-watered plants did actually contain more cells and larger cells, as well as more and larger breathing-pores (stomata) than the plants which were less thoroughly watered.

In the experiments recorded in the table, each jar contained 4 kilos of sand and 6 or 7 barley plants, which were supplied with all the food they needed. The amounts of water were so regulated that each jar received continually a certain definite proportion of it.

When the Soil contained Water amounting to Per Cent of all it could hold,	The Plants bore Seeds to the number of	There were harvested Milligrams of Dry Crop,
80	276	19,693
60	311	22,763
40	313	21,760
30	269	19,765
20	224	14,620
10	32	3,009
5	...	123[*]

Analogous results were obtained when barley was grown in jars filled with garden earth, and Hellriegel expresses his conviction that, for the generality of circumstances, an amount of water equal to about half what the soil can hold will be most advantageous on the whole. For experiments by the method of sand culture, he allows that the moisture may range between 60 and 40%, or even between 70 and 30% without injury to the crops.

The foregoing statements relate to experiments where the plants either had or had not water enough for their requirements from the beginning to the end of their lives. But many other experiments were tried, in which the plants were subjected to periods of thirst during one or another term of their development. From these trials it appeared that in the generality of cases the yield of the barley crop was very much lessened, even by short terms of drought, and that, no matter how copious the subsequent supply of water might be, the plants never fully recovered from the injury they had received. It seemed, moreover, as if the plants that had been particularly favored as to their supply of water suffered more from drought when it came to them, than those which had always had to put up with a somewhat inadequate supply of moisture.

It was constantly noticed that the periods of drought did more harm in proportion as they fell upon younger plants, and that those parts of the plant suffered most which happened to be in process of formation at the time when the drought set in. It is only when the barley plant has once happily reached the point that seeds begin to form in the young ears, that the success of the crop is assured. Thereafter the plants feel drought but little, and the process of ripening off can be finished very satisfactorily, even when the supply of water is small; that is to say, a very moderate amount of moisture in the soil is sufficient to provide for the translocation into the

[*] The plants formed three or four leaves, but no stem.

seeds of the ripening barley plant of the matters which had previously been stored in the leaves and stem and husks.

In the light of the foregoing results, Hellriegel has discussed anew the old question whether the rain that falls on a field during the term of growth of a crop can yield a sufficient amount of water for the proper support of that crop. He admits that an average crop of four-rowed barley in the vicinity of Dahme is about 23 bushels to the English acre, or, more precisely, 1,280 kilos of grain and 1,800 kilos of straw to the hectare; whence he computes that 3,300 kilos of dry substance, exclusive of roots, are produced to the hectare by the average barley crop of his locality. Now it has been shown, by his own experiments, that barley plants grown at Dahme exhale in the course of their lives an amount of water equal to 310 kilos for every kilo of dry substance produced above ground, whence it appears that 1,023,000 kilos or litres of water will be needed for each hectare of land bearing a crop such as the one now in question. Since a hectare is equal to 10,000 square metres, the amount of water above given represents a rainfall of 102.3 mm. to the square metre, or say 100 mm. during the term of growth of the crop, viz. from the middle of May to the end of July. If the crop were doubled, twice as much water would be needed, and if it were halved, half as much.

During the years 1859 to 1873 the average rainfall for the 2½ months when the barley was growing was 153 mm. The heaviest fall during this period was 226 mm. and the lightest 77 mm. But the foregoing calculations have reference only to water exhaled by the crop; no allowance has been made for moisture that evaporates from the soil itself, and it is not easy to make such allowance. Still, there is no doubt that large amounts of water do continually evaporate from the soil, especially during months so hot as June and July are, when the barley is growing. It is eminently probable, therefore, that the amount of water exhaled by an average barley crop, together with that evaporated from the soil, is fully equal to all the rain which falls during the growth of the crop. It is certain withal, that on several of the years above mentioned the rainfall at Dahme was wholly insufficient for the needs of an average crop, even if no account be taken of the moisture that evaporates from the soil. And even in the rainiest of years not so much water fell as would be exhaled by a barley crop of 46 to 55 bushels to the acre, such as is not unknown in favored regions. It must be borne in mind, moreover, how very irregular the summer rainfall is. There are often long periods without any rain. Showers are sometimes heavy and at other times light. Then, again, different soils vary widely as to their capacity of absorbing and holding the rain that falls upon them. Many soils are cultivated, indeed, which are palpably incapable of holding enough rain-water to support even moderately good crops. From all of which it appears, again, that the amount of water at the disposition of a crop is a point of paramount importance.

It was for the sake of enforcing this conception that Hellriegel asked the question, as previously stated, Does rain enough fall in a year at Dahme to supply a perfect barley crop? Even supposing that the rain could all be collected and stored, and be doled out to the crop during the growing season, the answer is clearly, No: not enough rain falls in that locality in a whole year for the support of a perfect crop, as will appear at once on inspecting the following figures. Hellriegel's best crops yielded at the rate of 42,359 kilos of dry substance to the hectare, which, multiplied by 310, the number of kilos of water exhaled by the plants for each kilo of dry substance produced, gives 13,131,290 kilos as the amount of water required; that is to say, a rainfall of over 1,300 mm. would be needed, while the average yearly rainfall at Dahme is only a trifle more than 551 mm., — less than half enough for the support of Hellriegel's maximum crops.

One Reason why Sands are Sterile.

In connection with his discussion of the inadequacy of the summer rainfall, Hellriegel made some highly interesting experiments on the amounts of water that might be held by the soil of fields in his vicinity after these soils had been soaked by the rains of winter. He found that a soil taken to the depth of 32 inches, which consisted of 13 inches of loamy sand tolerably rich in humus, 13 inches of loamy sand, and 6 inches of mere sand, could hold 1,164,483 kilos of water to the hectare; while the same depth of mere sand, viz. 32 inches, could hold only 418,600 kilos of water to the hectare.

These stores of water would correspond to the amounts supplied by a rainfall of 116½ mm. and of 42 mm. respectively. They mark the great difference in fertility between such sandy soils, and the deep mellow loams that are capable of being charged with — i. e. of holding — twice as much water at the start, which shall serve as a permanent source of supply to be supplemented by the summer showers. Such experiments as these illustrate most forcibly why it is that sandy soils, no matter how heavily they may be manured, can never give such good crops as deep loams unless indeed they happen to be placed in good relations with ground-water that is neither sluggish nor too cold.

As has been set forth in another connection, Hellriegel found that the weight of the seed sown had under some circumstances considerable influence on the yield of crop. The heavier the seed, so much the more vigorous is the young plant; but when the growing crop is provided with an abundance of food, under fit conditions, the advantage gained from heavy seed soon disappears. Where the crop is not well nourished, however, the benefit of heavy seed may be traced even up to the time of harvest, though it tends always to disappear. Several experiments which illustrate this point are given in the following table, which shows the absolute weight of the seed, in milligrams (same specific gravity in each case), and the weight of crop harvested 15 days after sowing.

Weight.	Green.	Dry
20	267	29
30	477	46
40	575	55
50	797	70

It is evident that, with heavy seeds, the probability of getting a good crop will be increased, in any event; and that such seeds are specially important in the case of forage crops which are to be mown before coming to maturity, and for countries liable to drought.

Yield of Barley.

Starting from Hellriegel's best crop, grown in a glass jar that contained some 29 lb. of earth, and calculating how much barley could be grown at that rate on an acre of land, it would appear that 18,818 lb. of the grain, i. e. 392 bushels, are possible; that is to say, an amount so much larger than has ever been grown in field practice that it is simply inconceivable. It is to be remembered, however, that, besides being much more numerous, the kernels of grain obtained by Hellriegel were larger and heavier than those usually grown in the field.

In England, the yield of barley varies from 15 to 75 bushels to the acre, the average crop being rated at 32 bushels for England and the South of Scotland. We do not do so well as that on this side the Atlantic. The United States census returns of 1870 show averages ranging from 12 to 35 bushels, the larger figures being those of California and Oregon. Here in Massachusetts the average crop of 1869 was 25 bushels to the acre. I have myself grown barley at the rate of over 60 bushels to the acre on plots of ground at the Bussey Institution, and 40 easily on still poorer land.

Composition of Barley Plants at different Stages of Growth.

Fittbogen has studied the question as to the periods of development when the barley crop takes in or produces the largest amounts of organic matter, ash ingredients, etc., in case the plants are grown under the best possible conditions, according to Hellriegel's plan. He cultivated plants in this way, and collected samples of them at five different periods as set forth in the following table. Each of his collections comprised twelve plants, which were dried and reduced to powder, and analyzed with the utmost care. At the close of the designated periods, the average development of the 12 plants was as follows: —

No. of the Period.	Date when Plants were taken up.	Length in Centimetres of		Number of the		
		Stalk or Leaves.	Roots.	Leaves.	Ears.	Seeds.
I.	22 May	113.4	6,794	70	...	...
II.	2 June	438.2	17,908	113	...	...
III.	16 June	983.4	33,265	120	12	...
IV.	24 June	1,034.8	33,830	123	13	329
V.	16 July	1,098.6	35,489	121	14	326

No. of the Period.	Date when Plants were taken up.	Weight in Grams when dry of the				
		Roots.	Stalks, Leaves, and Ears.	Whole Plant.	Grain.	Straw and Chaff.
I.	22 May	0.979	1.673	2.652	....	....
II.	2 June	2.209	5.801	8.010	....	....
III.	16 June	2.960	12.452	15.412	....	....
IV.	24 June	3.306	16.781	20.087	4.726	12.055
V.	16 July	2.676	19.222	21.898	9.247	9.975

The quantities of organic matter, ash ingredients, etc., taken in by the plants at the several stages of growth, will appear from the following tables.

One hundred perfect barley plants contained at the moment of collection the following amounts of substances, in grams: —

No.	Weight of the Organic Matter.			Weight of the Ash Ingredients.		
	Total.	In Roots.	Above Ground.	Total.	In Roots.	Above Ground.
I.	17.979	6.158	11.821	3.860	2.006	1.854
II.	60.752	16.669	44.083	5.139	1.739	3.400
III.	129.694	23.027	106.667	6.230	1.663	4.567
IV.	166.823	25.677	141.146	6.436	1.873	4.563
			41.250[1]			1.000[1]
			99.896[2]			3.563[2]
V.	175.726	20.764	154.962	6.693	1.538	5.155
			74.654[1]			1.388[1]
			80.308[2]			3.767[2]

No.	Weight of Nitrogen.			Weight of Phosphoric Acid.			Weight of Potash.		
	Total.	In Roots.	Above Ground.	Total.	In Roots.	Above Ground.	Total.	In Roots.	Above Ground.
I.	1.134	0.237	0.897	0.413	0.197	0.216	0.978	0.230	0.748
II.	2.043	0.438	1.605	0.615	0.161	0.454	1.116	0.165	0.951
III.	2.204	0.490	1.714	0.729	0.128	0.601	1.114	0.157	0.957
IV.	2.254	0.642	1.612	0.776	0.097	0.679	0.847	0.159	0.688
			0.661[1]			0.384[1]			0.229[1]
			0.951[2]			0.295[2]			0.459[2]
V.	2.252	0.583	1.669	0.802	0.077	0.725	0.809	0.079	0.730
			0.937[1]			0.566[1]			0.235[1]
			0.732[2]			0.159[2]			0.495[2]

[1] In grain.

[2] In straw and chaff.

It is evident that the plants continued to accumulate organic matter and ash ingredients as long as they continued to grow. Nitrogen continued to be accumulated until the end of blossoming. Both nitrogen and ash ingredients were assimilated with special ease and rapidity when the plants were young, i. e. during the first third of their life. Organic matter, on the contrary, was produced freely until the appearance of the ears. These results are made plain in the following table.

One hundred complete plants took in, absorbed, or produced the following weights of substances, in grams: —

No. of the Period.	Duration of Period, in Days.	During this particular Period.			Per Diem, on the Average.		
		Organic Matter.	Ashes.	Nitrogen.	Organic Matter.	Ashes.	Nitrogen.
I.	10	17.979	3.860	1.134	1.789	0.386	0.113
II.	11	42.773	1.279	0.909	3.888	0.116	0.083
III.	14	68.942	1.091	0.161	4.924	0.078	0.011
IV.	8	37.129	0.206	0.050	4.641	0.026	0.006
V.	22	8.903	0.257	0.000	0.405	0.012	0.000

It is to be observed that, although a continual increase of total ash ingredients was noticed, no such constant increase occurred in respect to some particular constituents of the ashes. Thus there were absolutely smaller quantities of potash, magnesia, soda, and chlorine in the plants during the last stages of growth than had been noticed previously.

The largest increase in weight of the crop occurred between the time when ears first appeared and the end of blossoming. A similar observation had previously been made by Scheven in respect to barley, and by Stoeckhardt, and by Wolff also, in respect to oats. But in the field, much must depend upon the character of the soil and the state of the weather, and Arendt has studied an oat crop which took up the largest proportion of its dry matter while it was comparatively young.

Taking the largest observed weight of the roots (dried) as equal to 100, there was produced of it, —

	Per Cent.
Before the 1st collection	29.6
Between 1st and 2d collection	37.2
Between 2d and 3d collection	22.7
Between 3d and 4th collection	10.5

From the time of the first appearance of grain until ripeness, the dry matter of the roots diminished to the extent of 19%.

For each 100 lb. of dry roots there were found the following amounts of dry stalks, leaves, etc. : —

171 lb. at the time of the 1st collection.
263 " " " 2d "
421 " " " 3d "
508 " " " 4th "
718 " " " 5th "

It is of interest to note how different these relations are from those observed by Nobbe in respect to the dry organic matter in the roots and foliage of buckwheat plants that were grown in garden loam. He found, namely, for 100 lb. of dry roots, 1520 lb. of dry stalks, leaves, etc.

Relation between Grain and Straw.

The relations between the amounts of barley grain and straw that are harvested in farm practice vary widely in different instances, and the consideration of the causes of these variations is a subject of no little interest. The perfect plants of Hellriegel yielded as a rule about as much dry grain as they did dry straw. His figures are 44 to 48% grain, 44 to 48% straw, and 6 to 8% chaff. Of course every particle of the plant above ground was saved in this case, and no kernel of grain was lost in any way, while in the field there is much waste, and often imperfect separation of grain from the straw. But it is none the less noticeable that in field practice the proportion of grain to straw is commonly as 2 : 3; at the utmost it is no better than 5 : 6. Boussingault found 78 grain to 100 straw, and Schwertz 38 grain to 100 straw. Under such conditions, it is no wonder that the straw is thought to have considerable value as fodder. It is held generally to be better for this purpose than the straw of rye or wheat. Manifestly, the more perfect the growth of the crop, and the more complete the ripening of it, so much the larger will be the amount of grain produced as compared with the amount of straw.

Limitations of Field Practice.

Curiously enough, when the question is considered in how far it is possible in field practice to attain results similar to those of Hellriegel, it will be seen that the farmer has less power over light than he has in respect to any other of the conditions requisite for growing a perfect crop. To control light in agricultural practice is quite beyond the power of man. The amount naturally available cannot be increased in any economical way, nor indeed can plants grown in the midst of a field, partially shaded as they are by their companions, ever get quite so much light as came to Hellreigel's individual plants that were entirely free from shade.

Heat also, speaking with regard to field crops, is almost as unmanageable as light, though some small increase of it can be gained by means of manures actually in process of fermentation, or by strewing dark-colored gravel on the land. Hellriegel constantly encountered differences from one year to another, both as to the amount of crop harvested, and as to the proportion of straw to grain, that depended on the comparative warmth of the several years.

It is the necessity of depending absolutely on the natural supply of light, and almost entirely on that of heat, which puts limits to the farmer's power of action, and holds him, so to say, in bonds; for every crop has its own peculiar requirements, both as regards light and heat, which he would be glad to have under control. At each period of development in a plant's life there is some special physiological work to be done, moreover, that requires some particular amount or degree of intensity as to the action of these agencies, which it would be well to supply or foster if it were but possible to do so. When grain is ripening, for example, the plants need, and they can bear, more heat than would be good for them when they are merely growing. So, too, a wheat crop needs more heat than a rye crop, and barley more than oats.

Other things being equal, it is in the last analysis the average heat and light of a locality which determine the kinds of crops grown there, and the amounts of each crop that are harvested. In all other respects the farmer has considerable freedom. By deep cultivation he might increase to almost any extent the volume of mellow earth at the disposal of the roots of a crop; by mulching, he could maintain good tilth; and by means of irrigation, water could be secured in abundance. And plant-food in any quantity might be added to the soil, either as manure or in the shape of artificial fertilizers.

The Germination of Seeds.

In speaking just now of barley malt, and in some of the earlier chapters also, the germination of seeds has been alluded to incidentally. It is a subject concerning which much might be said. Chemically speaking, the facts to be specially insisted upon are as follows. When a seed is moistened and placed where oxygen can come in contact with it, in a sufficiently warm place, the process known as germination begins. The conditions essential for germination are moisture, warmth, and oxygen; and if one or another of these conditions is lacking, the process will not go on. Even if the process were once well started, it would come to a stand-still if the water about the seed were to dry away, or the temperature were to fall, or the oxygen in the circumambient air were used up.

For example, seeds germinate readily when, after having been swollen in water, they are placed in a glass cylinder, which is kept warm, and through which a current of air is continually drawn, to remove the carbonic acid which results from the action of oxygen upon matters in the seeds. But if the current of air were checked so that carbonic acid could accumulate around the seeds, the process of germination would be interrupted; and so it is when seeds are buried so deeply in the soil that no adequate supply of air can reach them.

If swollen seeds are laid on muslin stretched across the mouth of a vessel full of water, they do not as a rule germinate so well as when placed in clayey loam, manifestly because the warmth evolved during germination is conducted away from the seeds more rapidly in the one case than in the other.

In order that germination on muslin shall be fully successful, it is best to keep the water beneath the muslin warm; that is to say, it should be maintained at the temperature best fitted for the germination of the particular seed upon which experiments are to be made. Some seeds germinate well enough on muslin when the water is at the ordinary temperature of the air, but others do not.

There is another point to be considered in respect to germination on muslin; viz. mere water is apt to dissolve out some albuminoid matters from the seeds, and this solution is prone to putrefy. To avoid this difficulty, it is well, instead of mere water, to use a mixture of one quarter of a volume of saturated solution of gypsum, and one volume of water. (Knop.) The lime salt forms insoluble compounds with the albuminoid matters, and prevents them from coming out of the seed. It is because of its absorption of these matters dissolved from the seed, as well as on account of its porosity and its comparative non-conductibility for heat, that clayey loam is a better material than either sand or sawdust in which to germinate seeds. One good way of proceeding is to place the seeds in a flower-pot saucer of common unglazed earthen-ware, which is set in a larger saucer kept filled with water up to the rim of the smaller inner saucer. Another way is to place the seeds on a strip of cotton flannel, and roll them up in it to a cylinder, the lower end of which is left resting in water kept at the bottom of a cup. The roll of cloth, and the seeds in it, are thus moistened by capillary attraction.

It is to be remembered, that a seed contains everything necessary for the development of the young plant excepting water and oxygen. Both these additions are necessary, and they must come from without. Seeds will not germinate in oil; nor in water which has been boiled to expel air; nor in gases other than oxygen. On the other hand, they are said to germinate well enough in air that has been compressed to half its original volume, and in that which has been rarefied to half the usual density.[1] Moreover, they do not require that the air about them shall contain the full quantity (20%)

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[1] More recent experiments, by Bert, cast a doubt upon the statement in the text. Bert found that, while 84% of barley germinated at the ordinary pressure of the air (= 76 cm. of mercury), only 40% germinated in air at 50 cm., 25% at 28 cm., and 6% at 10 cm. These observations have been supposed to support the idea that microscopic organisms play an essential part in the process of germination. It has been argued that germination cannot occur in presence of compressed oxygen, because the latter destroys all microdemes.

of oxygen which is usually found in air, though naturally enough too great a reduction in the proportion of oxygen is unfavorable.

By the action of air and water, at suitable temperatures, a tolerably large proportion of the insoluble matters in the seed are changed to soluble matters. A good part of the albuminoids change to diastase and maltin, and to asparagin, leucin, etc. The starch changes to dextrin and sugar. The oil in oily seeds disappears rapidly, and is changed first to starch, which in its turn ultimately forms the substances which build the shoot; meanwhile, much carbonic acid is evolved. All these soluble matters pass from the seed to the sprout, and are there changed to cellulose, starch, pectose, albumen, and the other matters of which the sprout consists. This transference of matter may even go forward, in the case of certain kinds of plants, for some little time from the lower leaves to those which are higher; and young plants may thus continue to grow in pure water for a month or six weeks, the lower leaves dying, meanwhile, as the upper leaves develop. Of course, under these conditions a little carbon is gained from the air through decomposition of carbonic acid which is absorbed by the leaves; but there is seldom any marked increase of dry matter over what was contained in the original seed.

It is important to remember that each and every kind of seed has its own peculiar limits of temperature between which it can germinate. A considerable amount of warmth is generated, of course, by the chemical reactions which occur during germination, but a certain external temperature is needed to start the internal development of heat. Maize needs a higher temperature for germinating than barley, rye, and wheat, in spite of the fact that the several grains resemble one another tolerably closely in chemical composition.

To test this matter, Hellriegel sowed several kinds of seeds, on the 15th of January, in glass jars filled with garden loam, and placed the jars in a room that stood between rooms that were heated, although it was not itself artificially heated. The earth was kept moist to the extent of 60% of its water-holding power, and the dates at which leaf-buds appeared at the surface of the earth was noted. Some of the results obtained are given, as an example, in the following table. The mean temperature of the soil was 48° during the experiment, and the range of temperature was between 43° and 53°.

Kind of Plant.	No. of Seeds sown.	No. of Plants that appeared finally.	At Days after Sowing.
Winter rye	10	9	9
Winter wheat	10	10	12
Barley	10	8	13
Oats	15	15	13
Maize	10	2	42
Flax	10	9	13
Peas	6	6	10
Horse beans	3	3	19
Lupines	5	2	42
Clover	20	17	14
Buckwheat	10	3	16
Beets	20	20	38
Carrots	20	20	38
Cucumbers	10	0	42

There is a curious practice of gardeners that deserves to be studied from this point of view; the custom, namely, of throwing the seeds of certain leguminous plants into boiling water, and letting the water cool with the seeds still in it. This "warming" is of the nature of a strong suggestion that the seeds should enter upon a new course of life.

Many experiments have been made, by different observers, to test the influence of various chemical agents on the germination of seeds. One point of practical importance that has resulted from these trials is, that many saline and acid solutions are detrimental to the process. Nessler found, for example, that most saline solutions that are stronger than 0.5% are hurtful, both for seeds and for young plants that have just sprouted. Thus, an 0.5% solution of common salt prevented the germination of clover, rape, and hemp seeds, though a solution so weak as this did not prevent wheat from germinating. A 1% solution of the salt, however, prevented all but a few grains of wheat from germinating, and the sprouts that did start soon perished. Hemp seeds were injuriously affected by a solution of salt that contained no more than 0.25%.

When moistened with a 1% solution of sulphate of ammonia, wheat grains germinated, but the young plants would not grow, not even when the solution was only 0.75%. A comparatively large number of seeds germinated when wet with a 10% solution of sugar, but the growth of the young plants was hindered even by a 0.5% solution of it. Ferrous sulphate (copperas), even when its solution is no stronger than 0.05%, has an injurious effect, both on germination and on the further development of seeds that have already sprouted. These statements consist with the well-known fact, that in water culture and sand culture it is usually safest to employ saline solutions that are no stronger than one part of the salt to 1,000 parts of water.

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CHAPTER XIX.

OATS.

The oat is a hardy plant specially well adapted for temperate climates. It yields a nutritious grain, besides straw that is held to be worth rather more as fodder than the straw of most other cereals. It is a plant which is easily grown, even in cold, harsh situations and on poor soils, being robust and vigorous, and capable of feeding closely, as the term is. That is to say, it is not fastidious, as wheat and barley are, either with regard to the quality of its food or the tilth of the soil.

It is because of these considerations that oats are often grown upon very poor land. So, too, in some of the older systems of rotation, oats were habitually grown at those times and places when the smallest amount of manure was applied. Yet oats are grateful for manure, and they thrive especially on soils rich in humus. They are frequently grown as the first crop on newly broken sod-land, and on peaty soils also.

Oats are not much cultivated in hot countries. In Europe they are rarely seen below the isotherm of Paris, while in Great Britain some 4,300,000 acres of oats were grown in 1880, mostly in Scotland and the North of England. In the United States rather more than 16 millions of acres were devoted to oats in 1880, against 35½ millions to wheat, nearly 2 millions each to barley and to rye, and 62⅓ millions to Indian corn. Oats succeed best in cool, moist climates, like that of Scotland and of Prince Edward's Island. In the vicinity of Boston oats are not grown, except to be cut green for forage, because of their liability to rust. In the Southern States, and in the South of England even, several varieties of winter oats are cultivated.

Oats not a Fastidious Crop.

In the matter of soil, as was said, the oat plant is not particular. It will grow upon gravel, or upon clay or peat provided the latter can be kept free from excessive moisture. It has often been said, that oats will grow upon any soil that can be ploughed and harrowed.

The yield in this country is from 10 to 12 bushels per acre in the Southern States, to 37 and 40 in Iowa and California, say 28 bushels on the average. It is about 30 bushels in New England. In the best oat districts of England and Scotland, they get from 44 to 56 bushels to the acre on the average, though occasionally 90 to 100 bushels to the acre are obtained from fertile fields.

Several interesting experiments have been made by Hellriegel with regard to the influence of moisture and of nitrogen on the prosperity of this plant. Starting with plants in tall pots, filled with sand capable of holding 25% of water, and mixed with all the constituents necessary for a maximum crop except water, he obtained the following results:—

Moisture in 100 Parts of the Soil.	Per Cent of all the Water the Soil could hold.	Grams of Crop produced.		
		Straw and Chaff.	Grain.	Total Crop.
2½–5	10–20	4.19	1.80	5.99
5–10	20–40	11.78	7.81	19.60
10–15	40–60	13.94	10.91	24.85
15–20	60–80	15.78	11.85	27.63

The plants did not wilt with the lowest proportion of water. Precisely as was the case with barley, Hellriegel observed that the natural rainfall at Dahme is insufficient to insure a maximum crop of oats.

In another set of experiments the plants had everything they needed except nitrogen. The following results were obtained when nitrogen was added in the form of a nitrate:—

Pounds of Nitrogen in a Million lb. of Soil.	Oat Grain harvested.	Oat Grain (calculated).
0	0.330	....
	Gain	
7	0.929	1.168
14	2.605	2.336
21	3.845	3.503
28	6.211	4.671
42	7.030	7.007
56	9.052	9.342
84	9.342	9.342

The point of special interest in this matter is, that similar experiments made with wheat and rye showed that a maximum crop of oats can be grown with a smaller proportion of nitrogen in the soil than is required by wheat, or rye, or barley. This result corroborates clearly the popular opinion as to oats, just now alluded to, and explains and justifies the practices of growing this crop on poor land, and on the least fertile field of a grain rotation.

Hellriegel has concluded from the results of his experiments, as stated in the table, that 56 lb. of nitrogen to the million lb. of soil are sufficient for a maximum crop of oats, while 63 lb. are needed for a crop of rye, and 84 lb. for a crop of wheat. Taking 56 lb. as the amount really needed, he has calculated the third column in the table, which represents the number of grams of grain which should have been produced by the amounts of nitrogen actually present in the soil in case the action of this element is proportional to its weight. These experiments, it should be said, are perfectly consistent with those of Stoeckhardt, who observed that the growth of the oat plant is greatly increased by the application of nitrogenized manures, and particularly by such as are easily soluble.

Mixed Nitrogenous Fertilizers good for Oats.

For actual farming practice Stoeckhardt recommended that the oat crop should receive a mixture of easily soluble and of difficultly soluble nitrogenized compounds, in order that the young plant might be made vigorous and the shooting plant thrifty by the former, while the older plant should be kept growing by the latter.

This recommendation is based upon the results of experiments which were repeated for several years. Stoeckhardt found that when soluble nitrogenized compounds were lacking, the crop did not prosper in the earlier stages of vegetation, while, if only soluble compounds had been given, the rate of growth fell off too soon after the plants had flowered. This difficulty could probably be met by applying the soluble fertilizer, nitrate of soda for example, by successive instalments, if that operation were but possible on a grain-field, though it may perhaps be true that the plants need one kind of nitrogenous food when they are young, and another kind later in life. By applying easily soluble nitrogenized manures, Stoeckhardt obtained vigorous plants at the start, a point upon which he insists.

He proved also that the mass of the oat plant could be increased by applying manure even after the plant had flowered. Hence he urges that the farmer should not be afraid of wasting manure by applying it to a young or middle-aged crop that happens to be backward, or that has received any check. He combats the notion that oats will not profit by a heavy dressing of fresh manure, having found that they bear such manure perfectly well; and he argues that it is a point for each farmer to determine for himself whether he had not better buy manure or fertilizers for his oat-fields, and so get good crops, rather than to scour the land by growing oats without special fertilization.

Bone-meal gave Stoeckhardt good results upon oats, even as a forcing manure, in case the bones had been steamed and ground fine, and it had the further merit of supplying nitrogen to the crop throughout its entire growth, almost. But it needs to be said that the Tharandt experimental field was a bottom land, little liable to suffer from lack of moisture.

Influence of Phosphates on the Oat Plant.

The following experiments made by Wolff, by way of water culture, to test the influence of different quantities of phosphoric acid on the development of the oat plant, are interesting, as showing how important it is, for successful growth, to have an abundance of this constituent, and how marked an influence it has on the production of the grain in particular. Eight jars, each containing six plants, were filled with a highly dilute solution that contained all the elements of plant-food excepting phosphoric acid, which was added in different quantities, as stated in the table.

No.	Milligrams of Phosph. Acid in the Solution.	Grams of Dry Matter in the entire Plants.	Grams of Dry Matter in the		Proportion of Grain to Straw.	Per Cent of Phosph. Acid in the Dry Matter.	Per Cent of Phosph. Acid in the Ashes of the	
			Grain.	Straw.			Grain.	Straw.
1	230.4	20.71	5.81	11.05	1 : 1.9	1.11	43.8	18.9
2	155.4	18.64	3.36	10.93	1 : 3.2	0.83	40.6	11.8
3	97.9	18.30	2.71	11.05	1 : 4.0	0.53	39.3	7.9
4	49.4	15.55	2.47	10.23	1 : 4.1	0.33	37.7	4.4
5	33.0	11.47	1.76	7.25	1 : 4.1	0.28	...	...
6	24.8	8.94	1.77	5.22	1 : 2.9	0.27	39.4	6.7
7	14.8	5.46	1.04	3.01	1 : 2.9	0.27	...	...
8	0.0	2.04	0.34	1.05	1 : 3.2	...	...	...

The percentage of phosphoric acid in the ashes of the grain shows how strong the tendency of this constituent is to move towards the grain, and the small amount of dry matter harvested when no more than 0.33% of phosphoric acid was contained in it points to the entire inadequacy of minute amounts of this material to perform the work that needs to be done. The plants in jars Nos. 5 to 8 attained to no great development in any of their parts. Under the influence of the larger amounts of phosphoric acid, the production of grain was abundant, complete, and assured.

Composition of the Oat Plant at different Stages of Growth.

The changes which occur during the growth of the oat plant have been carefully studied by several chemists, notably by Norton, Stoeckhardt, Wolff, Arendt, and Bretschneider, as has been set forth in "How Crops Grow," p. 204. The research of Arendt, in particular, was carried out in a very complete and admirable manner, and it is customary to lay special stress upon his results, although it is evident that in several particulars these results are of less general applicability than those of his predecessors.

In order to obtain a uniform material for his analyses, Arendt selected, from all parts of a 3½ acre field of oats, a number of vigorous, well-developed plants, of equal size, — as nearly perfect, in short, as could be found. He dried the plants quickly in the sun, and put them aside for examination. Collections were made in this way at five different periods, representing as many stages in the growth of the crop.

The first collection was of plants about four inches high, with three open leaves, and two leaves about to unfold. The second collection was taken when the plants were about two feet high, just before the end of the period of shooting up. The third collection was made just after the plants had blossomed; the fourth, when ripening had commenced, while the seeds were still soft, though they could be shelled; and the fifth, when the seeds were completely ripe.

The plants of each and every one of these collections were divided, in so far as was possible, into six portions; viz. into ears, two uppermost leaves, three lowest leaves, the upper joint, the two middle joints, and the three lowest joints; and each portion was subjected to analysis by itself.

As one result of this very elaborate research, it appeared that, although the oat plant increased in size and weight from first to last throughout its entire life, the rate of increase was surprisingly different at different periods.

By far the largest proportion of dry substance was accumulated during the time when the plant was shooting; while during the period of ripening the gain was very small, and it was mainly confined to the seed.

1,000 whole plants contained at the ends of the several periods, i. e. at the moment they were collected, —

	I.	II.	III.	IV.	V.
Grams of dry matter . . .	456	1,364	1,868	2,324	2,459
Organic matter	419	1,292	1,767	2,203	2,332

In other words, 1,000 plants absorb, take in, form, or produce, during the several periods, —

Grams of dry matter . . .	456	908	504	456	135
Organic matter	419	873	475	436	129

Too much stress must not be laid upon these figures, however, for results obtained by other experimenters show that a crop growing in the field may assimilate more or less of its substance at one or another period according to the weather and the soil, i. e. according as the supply of food is abundant or meagre, and as the conditions essential to growth are more or less favorable. For example, Stoeckhardt and Wolff and Bretschneider all found in their experiments that the oat plant usually gains more between the moment when the ear appears and the end of blossoming, than at any other time. Other chemists have noticed the same thing in respect to barley. Like Arendt, all these investigators noticed the increase of dry matter from first to last. But Stoeckhardt observed also, long before Arendt's research, that, when oats are manured with easily soluble nitrogenized fertilizers, the great increase of growth will occur before the plant comes into flower, and will fall off after the blossoming. This observation evidently explains the apparent anomaly in Arendt's results, for his oats were grown upon a field that had been dressed with guano the year before; and, as he takes pains to state repeatedly, the plants examined were all unusually rich in nitrogen.

Stoeckhardt observed furthermore, that, when the nitrogenized manure applied was of a kind that is difficultly soluble, the increased growth of the crop due to the manure, though at first scarcely perceptible, endured to a remarkable degree after the time of blossoming. This influence of manure applied late in the plant's life is no more than would be expected from what is known of the action of ammoniacal fertilizers on greenhouse plants. It is a fact familiar to many gardeners, that, when plants upon which flowers are beginning to appear are supplied with easily assimilable nitrogenous fertilizers, or even if their leaves are exposed to ammonia gas, the activity of growth will be transferred from the flower to the leaves and stem, which assume new vigor and extraordinary luxuriance. The following table, taken from Stoeckhardt's memoir, will illustrate the points just now mentioned. It gives the amount of increase of the oat crop in pounds per Morgen (= 0.631 acre) during the stated times.

	May 20 to July 5.	July 5 to July 25.	July 25 to Aug. 23.	Total in 96 Days.
No manure	555	545	335	1,435
With bone-dust	570	1,440	1,315	3,325
With guano and nitrate of soda	1,260	2,131	682	4,073

A similar result has been reported by a Danish farmer in the following terms. 240 square rods of oats that were dressed with 2½ cwt. of blood manure yielded 1,868 lb. grain and 2,225 lb. straw; with no manure, 1,584 lb. grain and 1,660 lb. straw; increase due to the manure, 284 lb. grain and 565 lb. straw.

Influence of Weather on the Oat Crop.

Stoeckhardt found also that the weather, according as it was cold or warm, moist or dry, had a marked influence on the movement of nitrogenized matters in the plant, not only as to the amount of nitrogen moved, but as to the times, i. e. the periods of growth, in which the movement occurred. The assimilation of nitrogen was checked by the cold, wet weather of the year 1851, for example, and promoted by the warm, dry weather of 1852. Whence the conclusion that pleasant, warm weather tends to the production of plump, highly nitrogenized seeds and non-nutritious straw, i. e. straw poor in nitrogen, while unfavorable cold weather tends to the formation of seeds poor in nitrogen, and of straw rich in that element. Stoeckhardt found the following per cent of nitrogen in the oat crops of 1851 and 1852: —

	1851.	1852.
Straw	0.57	0.28
Grain	1.09	2.00

He remarks that he heard constant complaint from practical men of the low value as fodder of the oats harvested in 1851.

A practical application of this knowledge would seem to lie close at hand. In the market of any large American city grain can be bought that has come from north, south, east, or west; and daily, monthly, and quarterly statements as to the weather in each section of the country are published. It is consequently within the power of the buyer to inform himself what regions have had special advantages for perfecting their grain, and to look in those directions in order that his money may be spent to the best advantage.

Another illustration of the power of the weather to influence the growth of a crop, even after the time of flowering, is seen in a practice of greenhouse men, of forcing plants which are about to flower to throw out leaves, and to increase the leaves that already exist, in case for any special reason they wish to retard the time of blossoming. To this end, the plant which is just ready to blossom is subjected to "bottom heat," i. e. the pot which holds the plant is set upon, or just above, the hot-water pipes by means of which the house is heated. An abundant increase of leaf surface is thus obtained, very much in the same way as it would be by feeding the plant with ammonia.

The influence exerted upon the crop by the mechanical condition or character of the soil is of course intimately connected with the weather. Thus, in the cold, wet year 1851, oats grown at Tharandt, upon very heavy land, contained 1.09% of nitrogen, while another parcel grown upon a less heavy (i. e. a medium) soil, contained 1.50%, and still another parcel grown upon a sandy soil contained 1.85%.

Taking all things into consideration, it is not strange that different scientific observers, operating in different places, under unlike climatic conditions, should have got results which vary from one another in several particulars. Compare, for example, Arendt with Bretschneider in "How Crops Grow," pages 205, 206.

It would be quite beyond the scope of this book to give all of the detailed tables which Arendt has drawn up for each of the six portions into which he divided the oat plant in each of the five periods, and for each of the component substances that were contained in the several portions. The book in which these results were published is in itself a considerable volume. But a synopsis of some of the more noteworthy results may be given in comparatively few words.

During the last half of the term of growth, after the plant had flowered, it may be said that the whole of the increase was on the part of the grain. There was scarcely any increase of dry organic matter in any part of the plant beside the grain, after the plant had flowered; and during the time when the plant was ripening, there was a slight diminution of organic matter in the upper leaves, and in the uppermost part of the stem. As for the lower leaves, they ceased to increase at the time of shooting, even before the plant had blossomed. The distribution of organic matter in Arendt's plants at the several stages of development may be seen from the following table. One thousand plants, at the different stages, contained in their several parts the given amounts in grams of dry organic matter:—

	3 Lowest Joints.	2 Middle Joints.	The Uppermost Joint.	3 Lowest Leaves.	2 Uppermost Leaves.	Ear.
When 4 inches high	76.76	....	....	179.86	162.58	....
After the shooting	120.16	178.85	127.88	199.23	286.77	387.34
After blossoming	135.29	228.24	204.28	198.11	327.47	674.02
Beginning to ripen	143.82	237.48	209.89	188.70	334.02	1089.14
Complete ripeness	141.55	231.01	205.84	179.94	327.53	1245.71

And 1,000 plants contained in their several parts the following amounts of ashes, in grams:—

Period I. . . .	3.54	...	...	19.34	13.72	...
" II. . . .	3.16	5.25	4.67	20.88	21.73	15.66
" III. . . .	4.91	11.46	11.32	22.49	24.53	25.70
" IV. . . .	6.68	12.52	12.41	21.31	35.98	31.86
" V. . . .	6.95	13.00	14.16	20.07	38.47	34.29

With regard to the separate "proximate constituents" of the oat plant, it appeared that cellulose is produced most abundantly at the time of shooting. It ceased to increase after the plant had flowered. One thousand plants contained the following amounts in grams of cellulose in the several periods:—

I.	II.	III.	IV.	V.
103	460	565	545	551

The largest absolute amount of cellulose, as well as the largest proportion of it with regard to the other constituents of the oat plant, was produced during the shooting up of the stalks, and the amount of this increase was not a little remarkable. Any given weight of dry plants contained twice as much cellulose after the shooting as before, but subsequent to that period there was hardly any increase.

An important lesson as to the harvesting of forage crops is suggested by these results; viz. that it would not be well to mow towards the end of the season of shooting, lest the proportion of mere woody fibre in the hay cut at that time be too large, as compared with the more valuable constituents. In general, a given weight of dry leaves contained less cellulose than the same quantity of stalks. In the dry leaves the per cent of cellulose ranged from 22 to 38. Up to the time when the plants blossomed, the percentage of cellulose was largest in the upper leaves; but afterwards it was largest in the lower leaves, because, as other substances passed into the upper leaves when the plants began to ripen, the proportion of cellulose there was diminished.

The least percentage of cellulose was in the ears, and it decreased moreover in these organs regularly as they grew older, and so became charged with other matters, from 27% at the time of flowering to 12% when fully ripe. The proportion of cellulose was always smaller, however, in the ears than in the leaves; and all the leaves put together did not contain so much of it as the mature stalk.

Throwing together the whole class of non-nitrogenized nutritious substances, such as starch, sugar, pectose, gum, etc., it appears that more of these things were produced during the shooting of the plant than at any other time, and that the least quantity was produced at the time of ripening.

On the whole, the stem is richer in these non-nitrogenized elements of food than the leaves; but as the plant grows older, the proportion of these ingredients increases in its uppermost parts, so that the higher leaves become comparatively rich in them. During the period of ripening, the proportion of the non-nitrogenized matters decreases to a notable extent in the middle and upper portions of the stalk, while it increases in the upper leaves and in the ears. It is evident that some of these matters are at that time transferred from the stem into the fruit and towards the fruit. Their increase in the ear is constant, from first to last. The large proportion of these matters in all the parts of the young plant is noteworthy.

One thousand plants, at the different stages, contained in their several parts the given amounts in grams of the non-nitrogenized elements of food: —

	3 Lowest Joints.	2 Middle Joints.	The Uppermost Joint.	3 Lowest Leaves.	2 Upper Leaves.	Ear.
When 4 inches high	46.47	. . .	. . .	83.10	71.85	[201.40]
After the shooting	60.91	91.89	68.97	79.37	106.10	217.47
After blossoming	66.90	124.95	99.51	82.36	139.44	424.02
Beginning to ripen	74.00	131.35	93.95	77.13	159.87	701.88
Complete ripeness	73.84	124.40	89.69	79.44	161.12	811.48

And 1,000 grams of the dried plants contained, at the several periods, these amounts in grams of the non-nitrogenized matters: —

Period I. . . .	566.08	. . . .	. . . .	416.87	407.56	. . . .
" II. . . .	493.73	521.75	512.55	360.62	344.21	539.53
" III. . . .	477.17	521.25	461.56	372.39	393.28	605.65
" IV. . . .	491.67	461.05	449.62	367.32	491.98	626.17
" V. . . .	497.22	446.83	431.39	397.24	439.81	634.59

Nitrogenized ingredients were found in the largest proportion in the very young plants; but as the plants grew older, the proportion of nitrogen fell gradually, while that of cellulose increased, until after the time of flowering, when (with the beginning of ripening) the amount of nitrogen suddenly increased to a remarkable extent, as will appear from what follows. One thousand plants took in (or formed) of nitrogenized matter, while very young, 95 grams; while shooting, 64; while flowering, 44; between flowering and first stages of ripening, 115; and during the last stages of ripening, 34. The young plants contained the following per cent of nitrogen: —

In the Stem.	In Lower Leaves.	In Upper Leaves.
2.15	2.34	3.74

But so far as these organs were concerned, the proportion of nitrogen in them diminished regularly as the plant grew, so that at the time of ripening the proportions were 0.79, 1.43, and 1.74. A table showing which parts of the plant were richest in nitrogen at the several periods is given in "How Crops Grow," page 212.

Until the grain begins to ripen, the leaves are richer in nitrogen than the ears; but during the process of ripening a large quantity of nitrogenized matter moves out of the leaves and stem into the ears, and from the lower leaves into the upper leaves. The upper leaves are, as a rule, richer in nitrogen than the lower, the tendency of the albuminoids being always to press forward in that direction. It is very noteworthy that about two fifths of the entire nitrogen in Arendt's crop were taken in between the time of flowering and that of very partial ripeness at which he made his fourth collection, and it was precisely at this period that nearly two fifths of the entire organic matter of the plant were produced. But, as has been said, Arendt's plants are known to be peculiar, in that they were unusually rich in nitrogen, as was perhaps no more than natural, in view of the fact that they were selected plants, chosen for the very reason that they were vigorous and luxuriant.

As for the roots of oat plants, experiments by Stoeckhardt have shown that they gradually become poorer and poorer in nitrogen as they grow older. Thus, in his crop of 1852, equal weights of roots contained sixteen times as much nitrogen when young as when ripe, and twice as much at the time of flowering as when ripe. This observation shows a reason for the well-known fact, that a crop grown after grain that has been cut green for forage does better than that grown on dry stubble.

Stoeckhardt found also, with regard to the husks of oats and other grains, that, although they finally give up the greater part of their nitrogen to the grain, and are consequently poorer in that element in proportion to their age, they do nevertheless still contain when ripe so much nitrogen that they are at least as rich in that element as the leaves, and much richer than the straw. This "chaff" is comparatively rich in mineral matters also, and the use of it as fodder is justified by these facts, to say nothing of the light grain and seeds of weeds which are apt to remain admixed with it.

Arendt gives tables to show the gain, in per cent, of each of the proximate constituents of the plant in the several periods, as follows: —

	Cellulose.	Fat and Wax.	Non-nitrogenized.	Nitrogenized.
I.	18	20	25	27
II.	63	30	32	18
III.	19	35	23	7
IV.	0	15	12	38
V.	0	0	8	10

Also to show the proportion of each ingredient at each period, assuming that the amount of it in the ripe plant is equal to 100: —

I.	18	20	15	27
II.	81	50	47	45
III.	100	85	70	52
IV.	100	100	92	90
V.	100	100	100	100

Ash ingredients were taken in by Arendt's plants continually until the grain was ripe, though the amount fixed tended to diminish as the plants grew older, and it received a decided check towards the close, when the cell membranes had become comparatively thick and hard. One thousand plants fixed the following amounts of ashes, in grams, in the several periods: —

I.	II.	III.	IV.	V.
36.60	33.48	30.33	20.34	7.18

It is interesting to observe that these quantities are not proportional to the amounts of dry organic matters formed in the same times, for these last are: —

419	873	475	436	129

This want of relation doubtless depends upon the fact that a good part of the ash ingredients of every plant are accidental and useless. The largest proportion of ashes (10.5%) was found in the ripe upper leaves, and the smallest proportion (2.56%) in the lower joints of the stalk at the time of shooting.

The percentage of ash in the ears decreased constantly in proportion as the grain increased in size, so that when the grain was ripe the percentage of ash in it (2.68) was almost as low as the smallest amount observed in the stem (2.56). Arendt has dwelt at some length upon the distribution of the several kinds of ash ingredients, and upon the times when they become part and parcel of the plant, but his results in that particular have not been supported by those obtained by subsequent investigators. Indeed, it does not appear that any assured knowledge upon these points has been acquired as yet, and it is plain that a crop, accordingly as it grows more or less vigorously at one time or another, may assimilate ash ingredients in very different quantities, and at different stages of development.

New Oats unfit for Working Horses.

There is one curious point in respect to the ripening of oats that has never been accurately studied. As all horse keepers know, new oats are unfit to be given to working horses. They loosen the bowels of the animals, make their flesh watery, or "soften them down," as the term is; i. e. they render animals apt to sweat easily, and, in general, put them "out of condition." How or why the new oats produce these effects is not known; but in the course of a few months after harvest, and especially after cold weather has set in, the oats undergo a change of some kind, either of after-ripening or of fermentation, and are thereafter fit to be fed out to horses. Probably this difference between new and old oats depends upon a change in the chemical composition of some one peculiar, and so to say medicinal, constituent of the oat grain.

Oats contain an Excitant (Avenin).

Another point to be noticed is the power of oats to excite and enliven, as well as to nourish, animals that feed upon them. It had long been debated whether there is not some peculiar chemical substance in this grain possessing medicinal properties to which this peculiarity might be due. This question has been studied by Sanson, in France, with the result that oats are found really to contain an excitant, to which he has given the name "avenine." It is a substance soluble in alcohol, and is, as Sanson says, capable of exciting the motor cells of the nervous system. To test the matter, he observed, with the aid of a graduated electrical apparatus, the nervous and muscular excitability of horses before and after doses of the avenin had been administered to them.

Curiously enough, he found that crushing or grinding the oats considerably weakens their power of excitation. Probably the air works to destroy the avenin. But the observation goes far to justify the common practice of feeding oats whole, in spite of constant and familiar evidence that the grain is not completely digested by horses when eaten whole. Every day, poultry, pigeons, and sparrows may be seen getting their living by picking out incompletely digested oats from horse dung. It may well be questioned, however, whether large consumers of oats might not find it profitable to crush the oats immediately before feeding them out.

CHAPTER XX.

ESTABLISHMENT AND MAINTENANCE OF HAY FIELDS.

There are many chemical questions relating to the cultivation of grass and the curing of hay which are still open for discussion. It would be extremely interesting, for example, to know precisely what kind of land is best suited for any given kind of grass, and why. Every farmer would be glad to know what kinds of grasses are best adapted to his own particular fields, and to know just what condition the soil should be brought to, in order to the utmost economy of production, both as regards fertility and fineness of tilth, and in respect to moisture at the moment of sowing and throughout the year.

Even the amount of seed to be sown on a given area is in some sort a chemical question, since the plants that spring from the seeds will struggle with one another for food, and will grow and feed differently, according as they are crowded or not. The depth at which the seeds should be buried manifestly depends on chemical considerations, — and it is, by the way, one of the most important points that the grass farmer has to consider.

How much and what kinds of manure should be applied to grass lands, and at what times, are other questions of very great importance; and so is the question in how far can the mulching of grass fields be made to supplement the process of manuring, or to make good a lack of manure.

The whole history of the growth of the crop, i. e. the knowledge of its condition and quality at different stages of growth, and the finding out of the best possible time for the cutting of grass, are matters which will be determined ultimately by the aid of chemical investigation.

So, too, with regard to the curing of hay, there are problems relating to the rapidity of drying, to the condition of dryness in which hay had best be housed, and to the comparative merits of storing it in barns or in stacks. It is still a matter of dispute among some farmers whether new-mown grass should be spread in the sun, or dried slowly in swaths, and windrows, and cocks.

Then, again, how shall mowing fields be taken care of, when once they have been established? Shall the sod be broken up every few years, or will it be well to try to keep the field in grass continuously for generations, as is sometimes done in Europe?

For the sake of convenience, it will perhaps be best to divide the study of grass husbandry into two sections, one of which shall relate to the hay crop proper, and the other to pastures and the care of them. And first as to hay, which is a highly important crop throughout the Northern United States.

Timothy preferred for Hay in America.

In New England, farmers have long been accustomed to look upon timothy (Phleum), or Herd's-grass as the local name is, as the representative grass, and to hold that it combines all the excellences which are to be found in a grass. The utmost they are ready to admit is, that a mixture of timothy and red-top (Agrostis), or of timothy and clover, may sometimes be advisable. It is probable, however, that this notion includes a considerable amount of error, and that sooner or later the discovery will be made that there are several other grasses worthy of being cultivated in this region, each of them in the places best suited to it. It would be indeed strange if, among the three or four thousand kinds of grasses now known to botanists, there should happen to be no more than one or two kinds suited to the climate and requirements of the Northern United States.

Probably this wellnigh exclusive growth of timothy is largely a matter of fashion, akin to the preferences for Baldwin apples and Bartlett pears which prevail in the same locality. Perhaps this fashion will die out in time, as that for the varieties of fruit just mentioned assuredly will, to judge from past experience relating to other varieties of fruit that were formerly esteemed and are now obsolete. It is noticeable, even now, that many pomologists stoutly deny the suggestion that the Bartlett pear is a fine fruit. Nevertheless, it may still be well, especially when speaking to New Englanders or to their descendants in Western States, to regard timothy, or a mixture of timothy and red-top, as the normal grass for hay.

As will be shown directly, timothy has one great advantage, in that it yields a very heavy burden of fairly good hay. It succeeds well on rich loams, even on peaty loams that have been well mixed with sand or gravel; and although it needs a fair supply of moisture in order that it may do its best, it is still true that on occasion it can support drought better than several other of the cultivated grasses, such as the meadow foxtail (Alopecurus) for example. But timothy is not in the least adapted to support long-continued hardship, such as insufficient food or permanent lack of moisture, and it is a mistake to sow it on land subject to these conditions. There can hardly be any adequate profit in growing this grass on light dry land, where most of it will die out in the course of the second year.

Methods of preparing Land for Grass.

There are two or three different methods of laying down land to grass, from the consideration of which some ideas may be got as to the condition in which grass land needs to be kept. In the vicinity of Boston, the commonest method is to till the soil during two or three years with hoed crops which are well dressed with manure, and then to seed down to grass, either with or without an addition of grain. By the continued tillage, the soil is well pulverized, its capillary condition is improved, and the manure is distributed throughout the soil. But another way of proceeding is merely to plough under the sod of an old grass field that needs to be renovated, to work in some manure, and to sow grass seed immediately, without any other tillage than that needed to smooth the furrows, stir in the manure, and prepare a shallow seed-bed.

Inasmuch as the chief motive in breaking up any old mowing field is to kill or check wild grasses which have "worked in," this method of simply turning under the sod may often serve a fairly good purpose, particularly on fields where the ground-water is not too far from the surface; and, if good, it is manifestly to be preferred to the other on many farms where hay is the chief crop. Wherever a fair profit can be got from corn, potatoes, roots, or other hoed crops, it would probably be best to interpolate such crops between the grass crops, according to the usual method, and thus charge the land with manure and bring it into a good state of fermentation; but it is none the less true, that the practices of most European countries where pastures and mowing fields are kept up for centuries, and are the more highly esteemed in proportion as they are older, go to show that rotation is in no wise essential for the successful cultivation of grass.

The partisans of the old method of seeding to grass after hoed crops, justly enough, urge the importance of bringing the land into a loose, porous, open condition. They insist on frequent ploughings as a preliminary to the seeding down of land, and there can be no question as to the benefits derivable from deep and thorough tillage in a climate so dry as ours. The power of tilling deeply and frequently is doubtless one of the merits of that system of seeding in which hoed crops precede the grass. But it is none the less plain, that the soil of many of the old European grass fields and pastures, on clay lands, for example, must be decidedly compact, — far more compact, indeed, than the soil would be after harrowing, and during the process of decay, on a field where the sod has been inverted.

The reproach is often made, it is true, against permanent grass lands, that since tillage and cultivation are notoriously beneficial to the soil, the lack of them must be hurtful, or at the least inadvisable. The argument is urged, that land which is never cultivated cannot be used to the best advantage, and that the exclusion of tillage from any particular fields can hardly be consistent with the most profitable use of those fields; and the same kind of objection will apply with a certain degree of force to the practice of seeding down to grass upon an inverted sod. But it may be answered to this claim, that it seems little short of absurd to break up old grass fields in situations not specially adapted for tillage, — such as steep, dry hillsides, for example, — when there is no urgent call to do so. In the supposed case, ploughing would destroy the native grasses, which have had no little trouble to work in and establish themselves, and, by the terms of the statement, the place is not well adapted for timothy or clover.

It has even been urged, sometimes, that the fact that the amount of organic matter (humus) is found to increase from year to year upon permanent meadows is an indication that the maintenance of such meadows must be irrational, since it shows that not enough air can come to the soil properly to oxidize its components. But there are several advantages derivable from permanent mowing fields that may much more than offset this particular objection, and in general it may be said that the small amount of labor required for the maintenance of permanent meadows would always give them precedence if it were but possible to get from them as large crops of hay as are grown upon new fields immediately after a year or two of tillage.

Stirring the Sod of Mowing Fields.

An experiment worth trying in certain cases, when seeding to grass on sod land, would be to run a subsoil plough through the furrows when the sod is turned. By so doing the objection as to inadequate tillage might be very much weakened, or perhaps wholly done away with.

The mere stirring of the sod of old grass lands has often been found beneficial. Thus a Massachusetts farmer reported some years since that he once, early in August, ploughed for half a day an old sod of 16 years standing, and during the next half-day occupied himself with his team and plough in turning this inverted sod back to its original position, i. e. grass side up. During the autumn, the piece thus ploughed grew green and strong, and could readily be distinguished from the rest of the field. Next year the crop of hay from the ploughed patch was at the rate of 1,300 lb. to the acre, while that from the adjacent unploughed land was at the rate of only 600 lb. to the acre. The good effects of this ploughing are said to have lasted during four years. Perhaps a part of the benefit obtained in this case may have come from the partial top-dressing of earth which the plough must have turned up, and it may be that the bringing up of buried seeds and the pruning of the grass roots were beneficial, but the inference is that the loosening of the soil was the principal advantage.

The question presents itself, whether, instead of turning the sods in this way, a considerable advantage might not be gained by running a subsoil plough directly through the grass, at stated intervals, across the field. A "subturf" plough has been invented and used in England for this purpose. But it has been suggested in this country, that, by putting a wheel on any good subsoil plough of moderate size, and running it through old sod to the depth of six inches or so, very effective work may be done at small cost for labor. The proposition was to make the cuts 12 or 14 inches apart in good growing weather in the spring.

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It would probably be well to follow the plough with a smoothing harrow, to scatter a small quantity of seed, and to roll lightly. The plan deserves to be tried on fields that have been so long in grass that there is danger of the crops becoming "bound out," as the term is; for it seems plain that any process of cultivation that can enable the soil to hold water to advantage, so that the crop may better withstand summer droughts, must be good for grass. There must be, in this sense, many fields where ordinary subsoil ploughing could be resorted to with advantage, just as, on the other hand, there are clay soils where the cost of tile drains would be repaid by the increased yield of grass.

Spring or Autumn Seeding.

The practices of farmers in Massachusetts with regard to the seeding of grass fields have changed considerably during the last fifty years. Formerly the spring was esteemed to be the best season for sowing grass seed, and this notion still persists in Maine. But nowadays late August or early September is very much preferred by most farmers in Massachusetts, excepting some exposed situations upon the seaboard, where there is little or no snow in winter. Probably the spring would be the best season for sowing grass seed if it were not for the summer droughts, which "burn off" the young grass, as the term is, and encourage a great growth of weeds that check it.

It may be questioned whether this change from spring to autumn sowing in Massachusetts may not be coincident with a general drying up of the soils, and the more frequent prevalence of summer droughts nowadays than formerly. Many parts of Maine are still well wooded, and much of the soil in that State is moist enough not to suffer, except in times of long continued dry weather. The much greater abundance of weeds upon land that has long been cultivated, than on land that has recently been reclaimed from the forest, is doubtless in itself one reason why spring sowing is less esteemed in the older State than it used to be. But in many parts of Maine the land must be still, comparatively speaking, new, and free from weeds in somewhat the same measure.

On heavy clay land that is not properly drained, it is said to be best to sow grass in the spring; for with such moist land the risk of burning off the young grass is small, and there is very great danger that the young grass plants would be winter-killed, through "heaving" of the land, if the seeds were sown in autumn.

Sowing of Grass with Grain.

It was customary formerly to sow always some kind of grain with the grass seed, whereas nowadays grass is very often, perhaps most commonly, laid down by itself without any admixture of grain. Wheat and barley were most esteemed among the grains for this purpose, and oats least of all, though oats would probably do well enough if they were sown thin. Some people in the more northerly States sow peas with their grass seed, and there are others who seed down in late summer and mix a small quantity of turnip seed with the grass seed. In that way they often get a good crop of turnips, without (as they claim) much injury to the young grass. In the vicinity of cities, where there is almost always a quick demand for straw, rye is probably the best grain to sow with grass, though in the vicinity of Boston there is a noticeable tendency nowadays to sow rye by itself and grass seed by itself without any admixture. One motive, probably, is to get superexcellent straw, free from any admixture of grass leaves.

Undoubtedly the question of sowing grain with grass is chiefly an economical question. In spite of all that has been said and written about the grain plants sheltering the young grass, and enabling it to "catch" well, it would seem that, in so far as the mere grass crop is concerned, grain must do more harm than good when sown at the same time as the grass. But, on the other hand, if the farmer wishes to grow any grain on his farm, it will usually be found most convenient to get a crop of it with the grass, even if it be somewhat at the expense of the grass, since there will be a great saving of labor in preparing the land and a real economy of land; for when the grain is harvested, and sunlight is thereby let in upon the grass plants, they are ready and waiting to grow up and yield a stubble crop in the autumn. But a crop like this, well established upon the land, is a much more satisfactory result, than a bare stubble field that needs to be dealt with at a busy season.

One advantage gained by growing grain and grass together is, that the supply of grain needed by a household can be got by cultivating only a small area of land. For example, if grass seed was sown by itself, and oats were sown by themselves, as much as 18 acres of land in all might be needed each year. But the desired amount of oats can readily be got by cultivating no more than 12 acres devoted to the mixed crop.

The fact is simply, that, when the farmers of New England grew their own grain, they sowed it with their grass seed. Now that they find it cheaper to buy grain from the West, they commonly sow grass by itself. Or, stated in somewhat different words, the grass crop has now become relatively so valuable in this section of the country that it pays best to cultivate it solely for its own sake, and to exclude all methods of cropping or tillage that would be likely to interfere with the growth of the grass.

The sowing of grain with grass seed has, of course, a certain analogy with the sowing of a mixture of different kinds of grass seeds, which is a practice that is very generally and very properly upheld. And, again, this idea of mixed seeds is somewhat akin to that article in the theory of the rotation of crops which depends upon the fact that different kinds of plants feed differently, both with regard to their power of taking substances from the soil, and as to the kinds of substances they take, or rather as to the times at which they take them. The methods of growth of grass and clover, for example, are so unlike, that the two plants can prosper side by side without greatly interfering with each other, and it is easy to believe that a grass which, like orchard grass, tends to grow in tufts, might well have some companion to grow with it in the interspaces.

It is said, indeed, that the tall oat-grass (French ray-grass = Festuca elatior) is sometimes grown at the West in conjunction with orchard-grass. Both these grasses grow rapidly, and ripen early in the season; they may be advantageously cut at the same time, and on strong rich soils they yield a good aftermath, or even sometimes two crops of rowen. But if the oat-grass can thus grow in the interspaces, why not oats, or some other of those kinds of grass that are commonly called grains?

There is, indeed, small room to doubt that there are some advantages which tend to counterbalance the disadvantages of growing grass and grain together. Hence the conclusion that the growing of grain with grass is clearly admissible in many cases. One trouble may be that grain saps the surface soil too much at the very time when the young grass plants have most need of abundant food in order that they may become firmly rooted. Moreover, the grain plants must steal water from the young grass, as well as food, when the two kinds of seeds are sown together. These difficulties are in some measure avoided by sowing the grass seeds in the spring on winter grain that has already started to grow, as will be shown directly.

Grass Seeds must not be deeply buried.

As to the methods of sowing grass seeds, experience teaches very emphatically that the seeds should not be buried deeply in the earth. Large-sized seeds, like peas, and maize, beans, lupines, and the like, may be buried pretty deeply without much harm. They contain a sufficient supply of nourishment to carry the sprout happily through a considerable layer of earth; but little seeds, like grass seeds, have no such power, and there is great danger of losing them altogether if they are deeply covered.

It is true in general, that, wherever seeds can be kept properly moistened, they should not be buried deeply, and this both because the seeds need air, and because of the risk of placing too many impediments in the way of the young shoot. The distance through which the shoot must pass in order to get above ground should be as short as possible, in order that the store of nourishment in the seed may not be wholly expended in the struggle with the layer of earth above the seed. Some of this store of nourishment is needed to establish the young plant firmly after it has reached the air.

One of the commonest ways of sowing white clover is to scatter the seed upon the last snow that falls in the spring, and leave it to take root upon the surface of the wet soil. Grass seed is sometimes sown in the same way, and there seems to be little doubt that it would be a highly successful way, if the seed and the surface soil could but be kept continuously moist while the seeds were germinating and the young plants were striking root. Clover is said to do specially well when sown on snow, provided it has not been threshed and winnowed, but left in the husks, so that moisture can the better be retained upon it. The very fact that grass seed can germinate and grow under these conditions points of course to the conclusion that there is small need of burying it deep in the earth. But there are plenty of methodical experiments which show directly that deep burying is not only unnecessary, but hurtful to the last degree; and the same lesson is enforced by the enormous number of grass seeds that farmers are in the habit of sowing upon the acre of land. Very little figuring is required to show that a large proportion of the seeds sown never come to any good, and the conclusion lies near at hand, that most of the missing individuals have been buried beyond all hope of recovery.

As was just now intimated, there would be little need of covering grass seeds at all, if the young plants could but be shielded from winds at the moment of starting, and the surface of the ground be kept moist during the germination of the seeds and until the young plants were firmly established. But in practice it is commonly necessary to give the seeds a slight covering of earth, in order that they may not become dry, and that the young plants may have such a hold upon the earth from the beginning that the wind cannot throw them about in every direction, and loosen their connections with the soil.

Methods of Sowing Grass.

In this vicinity the common method of procedure is to brush in grass seed, or to harrow it in very lightly, and then roll the surface of the land smooth. Some farmers prefer a light plank drag or "smoother," which is drawn rapidly over the ground with a pair of horses. But neither brushing nor harrowing is necessary to bury the seed in case a proper seed-bed can be prepared in the first place. When this can be done, the mere process of rolling or of "planking" is all-sufficient, both for burying the seed and "firming" the soil; though there are many fields, of course, too rough or stony for the roller or the plank to do good work, where a brush harrow will need to be used.

When all the conditions are favorable, a good way of sowing grass seed would be somewhat as follows. Starting with land that has just been ploughed, it might be harrowed across to smooth it somewhat, then dressed with manure, and harrowed to work in the dung; then bushed again and again, if need be, or worked with a smoothing harrow until a thoroughly smooth and even surface has been obtained. Upon this perfect seed-bed the grass seed is sown and rolled, or planked in, as was said; or, if the roller be inadmissible, the seed may be covered in with a light bush. The main point is to smooth the land completely before the seed is strewn, so that none of it may be buried too deeply.

The process of rolling or planking has the very great merit of bringing the seeds and the soil into intimate contact with each other. Thanks to the compaction of the soil, moisture can rise in it by capillary attraction to the very surface, and both the soil and the seeds are kept moist enough for the latter to sprout. Many little clods are crushed by the roller or the drag, and the soil and seeds are duly mixed. All this beside the merely mechanical advantage of making the field smooth, and fit for the passage of mowing-machines, scythes, and rakes. Of course the roller would not be used unless the land were sufficiently dry for it.

When grain is to be sown in conjunction with grass, the operations will need to be carried out in a somewhat different way from those just described, for the grain should be buried deeply enough to protect it from the ravages of birds, and to hinder those of mice and squirrels. Grass seeds are so small that there is comparatively little risk of their suffering in this way, and after the roller has passed over them they cannot be blown away.

In laying down land to grass with grain, it would be but natural to try to save as much trouble as possible. An ignorant person might try to have the two kinds of seeds scattered simultaneously, and might then harrow the land deeply enough to cover the grain completely. But this method of procedure would be inadvisable, because the small amount of labor saved would not compensate for the grass seed that would be destroyed by the deep burying of it. An uneven stand of grass would be obtained, moreover, which would be uneconomical. There can be little doubt that a good part of the ill repute in which the plan of seeding grass with grain is now held, really depends on the results of vicious practices which were formerly employed, without any just conception of their bearings and effects.

Nowadays, the best farmers, when seeding down grass with grain, take care to avoid the risk of losing grass seed by sowing the grain by itself in the first place, and harrowing it in before they scatter the grass seed. The operation remains very much as was just now described for grass alone, with the exception that the grain is sown before the field has been made completely smooth, so that the trouble of harrowing in the grain amounts to nothing, inasmuch as it represents one step in the process of smoothing the field for the grass.

In the moist climate of Scotland a different method is adopted. Thus, upon farms in the immediate vicinity of Edinburgh, at the present day, "Grass seeds are generally sown along with the barley crop. When barley has been put down early, the grass seeds are sown after it has come up well, because, if they are put in at the same time, the grass gets to be too profuse by harvest time, and causes great difficulty in securing the drying of the sheaves for the stack. In a favorable season sowing begins by the middle of April. Nowadays the seed is almost universally deposited by a drill 16 or 18 feet wide, and is covered in, either by a very light stroke of the harrow, or by a turn with the roller. The latter plan is mainly adopted, and is to be recommended because the nearer small seeds are to the surface the better."

In this country also, a common modern method of sowing grass is to harrow winter grain in the spring, strew the grass seed, and go over the field with a roller. This method has undoubted merit, and the more particularly because the harrowing helps the growth of the grain. The idea is, that if wheat or rye is harrowed in the spring, as soon as the ground is dry enough to bear a team, the crust upon the surface of the land is broken, and many small weeds are destroyed while the grain plants get a start. It is said that on grain alone some farmers repeat the harrowing (using a smoothing harrow) every week or two until the plants are a foot high.

There is, withal, another point to be considered. When grass is sown on grain in the spring, the competition between the two crops must be much less keen than when grain and grass are sown together in the autumn. For when sown in autumn both crops will pass into the root-striking stage simultaneously, and in the same layer of soil, and it would seem that they must necessarily tend to steal food from each other. But in the spring the grain roots are already developed before the grass is sown, and they have in good part grown down out of the surface soil, so that the young grass plants find an empty room, comparatively speaking, and they have a fair chance to develop their system of roots without material hindrance at a time when the grain plants are shooting.

Under these conditions, indeed, the grass seeds may have an exceptionally good chance to germinate, since the shade cast by the grain tends to keep the surface of the ground cooler, damper, and less subject to sudden changes of weather, than it would be if no crop were growing upon the land, and the dew also which trickles down the grain plants goes to help the young grass. Under the shadow of the grain crop there will be much less risk of the young grass plants burning off during any short spell of dry weather, than there would be if they were fully exposed to the sun and wind. But when once the grass crop has become firmly established, then the shade of the grain must be injurious to it, and when the grass roots have penetrated far enough to compete with those of the grain for water and for food, then each of the crops must do more or less injury to the other. Practically, however, the grain will be ripening off, or even be cut down and removed, before much harm can be done to it or by it in the competition.

Experiments with buried Grass Seeds.

Mention may here be made of some of the details of methodical experiments which have been carried out with regard to the proper depth of burying grass seeds. Hoffmann's experiments, cited in "How Crops Grow," p. 317, show that clover will not germinate, even under conditions that are in other respects favorable, when buried more than 3 or 4 inches. The grains, on the other hand, came up from a depth of 8 inches, and peas and corn from a depth of 10 inches. All the kinds of seeds that were tried by Hoffmann perished at 12 inches. Experiments by Lawson showed that grass seeds need only a very light covering of earth. From nothing to one quarter or half an inch he found to be the best depth. Some kinds of seeds did not come up at all when buried a single inch, and few kinds came up at all when buried two inches.

A German experimenter, Jessen, who tried many kinds of grasses, has corroborated the results of Lawson. With timothy seed, for example, he found that less than half the number of seeds sown half an inch deep came up either in loam or in sand, while all the seeds grew when they were sown 0.06 inch deep. Orchard-grass did even worse than timothy, i. e. the percentage of seeds lost by burying was greater. The general conclusion drawn from these experiments is, that grass and clover had best be buried no deeper than 0.03 in. on heavy land, and from 0.1 to 0.15 in. in sandy loam. In good medium loam they may be buried 0.05 in. in a moist season, and 0.1 in. in a dry time. The grains, on the contrary, should be buried about $\frac{1}{10}$ of an inch deep in heavy land, and $\frac{4}{10}$ of an inch deep in sandy loam. In loam of medium quality $\frac{1}{4}$ of an inch will be a good depth in moist weather, and $\frac{1}{3}$ of an inch in dry weather.

In very dry situations, however, it may be best to sow grain rather deeper than this, as the following experiments of Hosaeus go to show. He operated in dry autumn weather on a light soil that dried out very easily. Parcels of wheat, each containing 100 grains, were sown at various depths on separate beds on the 5th of October, the day after a heavy rain, and the numbers of living plants were counted on the 18th and 25th of October, the 6th of November, and the 10th of December. From the 5th to the 19th of October the weather was warm and clear, with cool nights and much dew; from the 19th to the 25th of October it was cold and rainy, and from the 25th of October to the 6th of November continuous dry weather. Thereafter the weather was changeable, with but little rain. The trials were in duplicate, as stated in the table. It appeared that for so light a soil in dry weather a depth of from ¾ of an inch to an inch was best for wheat. The shallow seeding of ⅓ inch gave somewhat less satisfactory results.

Depth at which the Seeds were buried, in Centimetres. (1 cm. = 0.394 inch.)	Of 100 Seeds sown there were visible Plants on			
	18 Oct.	25 Oct.	6 Nov.	10 Dec.
1	45	70	73	73
	47	79	87	87
2	87	90	88	83
	87	96	98	98
3	88	93	93	89
	92	94	97	94
4	65	88	87	84
	74	92	95	89
7	34	82	82	81
	36	80	80	79

Heavy or Light Seeding?

The certainty of loss when grass seeds are buried too deeply explains why it is that many excellent farmers are in the habit of sowing what seems to be a very large number of seeds upon the acre of land. In fact, the amount of seed that had best be sown is a question which has been much debated. There are many farmers who believe that the besetting sin of New England is to sow too lightly for grass; while others think that what is known as heavy seeding is mere folly and ignorance. As matters have stood hitherto, the advocates of heavy seeding have probably been more nearly right than their opponents, for it is plain that, if all the seeds that fall into cracks and holes in the land are to perish, as well as all those that happen to be buried under clods or the like, there must be a large allowance made for contingencies. How large this allowance commonly is in this vicinity may be seen by consulting Mr. Flint's "Treatise on Grasses." About 15 seeds to the square inch, as he computes, are commonly sown, while no more than 2 or 3 grass plants are grown to the inch, and often not so many. In other words, it may be said that some 2,200 seeds to the square foot are commonly sown by the best farmers in Massachusetts, while ordinary pasture sod contains only some 200 to 900 plants to the foot. Some very rich old pastures contain 1,000 plants to the foot, and as many as 1,800 plants to the foot have been found in the sod of a superlatively excellent irrigated meadow.

Some allowance has to be made, of course, for bad seed; but the probabilities are that much more seed has been sown hitherto to the acre than would be proper if all the practices were perfect. Clearly, there should be less need of seeding heavily nowadays than there was formerly, since much greater pains are now taken to smooth off the land before seeding it, and especially since the seeds are rolled in, or at the most lightly brushed, instead of being harrowed.

Nevertheless, it must never be forgotten that the infant plant, as well as the new-born fish, is subject to many calamities. Mr. Darwin took pains to mark all the seedling weeds that came up on a plot three feet by two, which had been dug over and cleared so that there could be no choking from other plants, and he found that out of 357 little plants that came up no less than 295 were destroyed, chiefly by slugs and insects. This result emphasizes the importance of liming land, as is often done in England, merely for the purpose of clearing it of such pests as these.

Instead of seeding heavily with one kind of grass, and seeking in this way to overcome all opposition, it would seem to be best to devote one's energies to preparing the land so thoroughly that it may hold a great store of moisture for the support of the crop, to careful seeding, and to the sowing together of two or more kinds of well-chosen seeds. There is no real difficulty nowadays in obtaining from seedsmen as large a variety of grasses as one may wish to grow.

Winter-killing of Grass.

One great trouble in respect to grass in the climate of New England is to have the young crop "get a good catch," as the term is; that is to say, to have the young plants well started and firmly established. Against this desideratum, both the winter's cold and the summer's heat work very emphatically. There is, upon the one hand, the danger that the young grass that has been sown in the autumn or late summer will be "winter-killed," and, on the other, a nearly equal risk that the young grass will be "burnt off" by the sun's heat in times of drought, both in the autumn and in the summer.

It is not so much the cold of winter that kills grass, as the freezing and thawing weather of spring. Even when a winter is open and free from snow, young grass that was sown in the autumn may be seen looking very well as late as February, and yet perish miserably, for the most part, between that time and April. It is generally recognized that steady cold weather does comparatively little harm to grass, even in the absence of snow; and that it is processes of repeated freezing and thawing that do mischief, by continually expanding and heaving up the surface soil, and so stretching and tearing the grass roots. This view is undoubtedly correct; but it is none the less true that extreme cold is of itself hurtful to some of the better kinds of grasses, especially when the plants are young. Grass fields upon exposed hillsides and ridges, where the winter winds have full sweep, are extremely liable to suffer from winter-killing, even when the weather is so cold that there is little or no chance for alternate freezing and thawing.

On the other hand, young grass suffers severely upon fields that are so flat that rain-water can stand in puddles upon the land after the earth has frozen. Here the chief trouble seems to be, that, when the water in the puddles freezes, the ice encloses the grass stems and pulls them up, or tears them from the roots as it expands. Low and undrained land is commonly worse in this respect than flat upland, chiefly, perhaps, because there is more time for this kind of action to occur upon it; for after the ground has once frozen in our climate, there is small chance for the soaking of water through it, no matter how good the drainage may be in spring or summer. Of course, the winter is apt to begin a little earlier in the low land, and to last there longer than on the ridges, and the continued wetness and coldness of the low-lying land in the spring, after the frost has left the ground, may work against the recovery of any grass that has been crippled during the winter.

Snow protects Grass.

When the ground is thoroughly covered with snow during the winter, but little grass is winter-killed; and it was a common saying formerly in New England, that hay would naturally be abundant and cheap after a winter of frequent and enduring snows. Indeed, in most cold countries, a good depth of snow is thought to be highly beneficial to the farmer, by protecting grass and grain from severe spells of weather.

The snow is at its best when it lies light and loose, and evenly upon the land. After it has been exposed to long-continued cold, and particularly when solidified by processes of alternate thawing and freezing, snow shrinks in upon itself, and loses much of its protective power. The more nearly a bed of snow resembles ice, so much the deeper will the soil beneath it freeze in cold weather. A covering of ice is bad for grass, as may be seen, for example, almost any winter in Boston in the yards on the shady (north) fronts of dwelling-houses. It will be noticed that in these yards the ground freezes deeply beneath the ice which covers the surface in late winter, and that the grass is often destroyed wellnigh completely. Undoubtedly this grass is exposed to a low degree of cold, but it would seem also that the thick layer of compact ice must actually smother the plants by preventing any air from coming in contact with them. It is true, even of hibernating plants, that processes of life go on within them, and that the plants need to breathe in some oxygen and expire some carbonic acid. It has been noticed in the mountainous parts of Europe, that fields of winter grain are apt to suffer injury when the land remains too long covered with very deep beds of snow; and it has been argued in this case also, that the injury to the crop is caused by the lack of light and air.

In any event, ice, though commonly accounted a bad conductor of heat, can hardly be compared with snow in this particular; for, as it occurs in the fields, the loose, light-lying snow encloses a large amount of air in its interstices, and this air, being an excellent non-conductor of heat, tends to prevent the escape of heat from the soil, and greatly hinders the penetration of frost. The ground usually freezes to a much greater depth in snowless winters than in those when snow abounds. It has been reported of the region about Lake Superior, where more or less snow falls almost every day during the winter, and the accumulation of it is enormous, that the first fall usually occurs before the ground has frozen, so that the soil is protected from frost to a remarkable degree. Vegetables, such as turnips and potatoes, that have been left standing in the ground there may be dug at any time after the cold weather has set in, by first removing the snow that covers them; and it is said to be a common occurrence for such crops to renew themselves there without successive plantings.

Spring Rolling of Grass Fields.

It is commonly tanght that it is well, where young grass has suffered from frost during the winter, to go over the field with a roller in the spring, for the purpose of firming the land, and of crowding back into the soil the roots that have been torn or loosened by the expansion of the ice. The practice is probably a good one if the right moment for the rolling can be hit upon, — when the ground has become dry enough to bear the horse, and to let the roller pass without sticking or clinging to it, and before the roots have been exposed to the wind and sun. The probabilities are, however, that if such grass land is rolled at all in the spring, it will be best to scatter a little fresh grass seed just before that operation. On stony land another advantage is gained, of course, by the rolling, since any loose pebbles that may be lying upon the surface of the land are pressed into the soil out of the way of the scythe or the knives of the mowing machine.

Burning off of Grass.

As for the opposite risk of "burning off," that may occur in summer in times of drought, or in case the seed is sown in autumn it may occur then also if there has been a drought during the summer, or if a specially dry spell of weather should happen to follow the sowing. If grass is sown in August upon a dry field, there is risk of the seeds sprouting by virtue of moisture obtained from dews, or from an occasional light rain, and that the young plants will die afterwards in case there should come a few days of hot dry weather before the ground has been thoroughly soaked by the autumnal rains. It is for this reason that, in dry seasons, farmers are loath to sow grass seed in August, except on low-lying land, or on land that is well provided with ground-water. They like to play a sure game, by keeping within the influence of the "line storm," as they say (September 21), although it is a well-recognized fact that, were it not for this risk of drought, it would be far better to get the grass seed started in August than to wait until September, since the older the plants are when winter sets in, so much the better will they withstand the rigors of that season.

Power of Young Plants to resist Drought.

Something may be judged, perhaps, of the power of very young grass to withstand drought from the experiments of Nowoczek on other kinds of plants. He caused seeds to germinate on moistened flannel, and when their roots and sprout had attained a length of 1 cm. (= 0.394 inch) he dried out the flannel together with the young plants at a temperature of from 60° to 68° F. The flannel was then moistened anew and again dried, and the processes of moistening and drying were repeated as long as any of the plants were alive. His results are given in the following table, whence it appears that germinating seeds of wheat, barley, and rye have an extraordinary power of resisting drought. It was seen that the rootlets died completely every time the young plants were dried, and that new roots were developed when the plants were again moistened. The leaf shoots also dried off at their points, but the internal organs remained alive, and developed new parts on being moistened, even when the shoots had attained a length of ¾ of an inch or an inch. Oily seeds, and those of peas and clover, exhibited very much less power of resisting drought than those of the grains proper.

On Oct. 24 there were laid out to germinate 100 Seeds of	Up to Oct. 31 there had germinated	No. of Plants that grew again after each Drying: —					
		2d Drying to Nov. 10.	3d Drying to Nov. 27.	4th Drying to Dec. 9.	5th Drying to Dec. 25.	6th Drying to Jan. 5.	7th Drying to Jan. 18.
Wheat	75	70	57	31	25	10	1
Barley . . .	85	78	74	40	33	17	4
Oats	90	83	77	62	40	27	8
Maize . . .	98	96	66	14	3	0	0
Rape . . .	85	55	27	17	1	0	0
Flax. . . .	88	78	30	9	0	0	0
Red clover. .	85	41	10	3	0	0	0
Peas. . . .	87	38	3	0	0	0	0

Even the grass of old fields may be partially killed off in midsummer by excessive heat, particularly at those spots where the larvæ of the June-bug or other enemies have been devouring its roots. One way of lessening this risk manifestly is to abstain from mowing the fields too closely, so that the grass shall not all be cut off close to the roots. If a joint or two of the stem and some leaves are left, for the plants to breathe and feed by, the grass will naturally stand a somewhat better chance of resisting hardships than if the plants had been shorn off close to the earth. For in spite of the fact that such lower leaves might be old and feeble they could still do something towards supporting the roots at a critical period. So too, if grass is mown when tolerably young and vigorous and not yet dead ripe, there will be comparatively little risk of the roots being killed by heat.

One sure way of giving the plants a new start after mowing would be to irrigate the field immediately after the hay had been carried off it. There will be much less trouble from the sun's heat when grass lands come to be irrigated than there is now. In a region where the summers are so dry as they often are in New England, irrigation is the one thing needful for the support of grass upon most upland hay fields and pastures. It is a method of husbandry which the American people have got to come to sooner or later, and the remark will apply even more forcibly to the Southern and Middle States than to those at the North. There is small reason why permanent water meadows should not be established in many parts of the South, from which grass should be cut pretty much all the year round, as has been done in Lombardy time out of mind.

Top-dressing Grass Fields.

Excepting some special localities, where top-dressing is habitually practised, it would appear that American mowing fields seldom receive any other manure than that applied at or before the time of seeding; the small amount of dung dropped by cattle that are allowed to roam over the land in autumn being hardly worthy of mention. It is true enough that most farmers recognize the fact that grass is a crop that needs to be well manured in order that it shall give a large yield, and that they have on the whole a favorable opinion of top-dressings, but in point of fact this method of applying manure is not much practised excepting as regards lawns, garden borders, and banks about houses. Most farmers are agreed, moreover, that mere dirt is useful as a top-dressing, even in cases where it is not to be supposed that it can have any direct action as a manure, and they are thus naturally led to look with much favor upon peat composts.

There is no doubt that a thin coating of loam laid on in very early spring, or in the autumn, may have an important influence for good in covering roots that have been torn by the winter's frost, or that would be so torn if they were not thus covered; and on this account there must always be a certain advantage in using stable manure or compost for grass lands instead of mineral fertilizers. Peat composts, fermented with dung, are clearly indicated for this purpose. Whatever seeds of weeds there may be in the stable manure will do comparatively little harm upon the grass, where many of them will come to nothing because of the processes of cutting and smothering to which they are subjected. It is noteworthy that in the region near Portsmouth, N. H., where sea-weed is the chief manure, the farmers often strew their stable manure upon the grass land and promote clean culture by using the sea plants, that cannot by any possibility introduce weeds upon their plough-land. If not enough compost can be made with dung, wood ashes may be used to ferment the peat; or, in default of ashes, or potashes, lime may be used; or a mixture of lime and muriate of potash.

In applying manure to grass fields in northern countries it will assuredly be well to do so tolerably early, whether it be done in the spring or in autumn. Just as in the spring no prudent person would wait until the ground was soft enough to be poached by the feet of animals and rutted by cart wheels, so in the autumn the application of manure should not be delayed until the beginning of winter when the ground has frozen so hard that none of the goodness of the manure can soak into it. There will be some risk, of course, if the land be top-dressed too early in the autumn, that too rank a growth of aftermath may be excited, and although a tolerably thick bed of dead grass upon a field may be an excellent protection against winter-killing, it is objectionable in that it affords shelter for mice that eat the grass roots, and that the land is encumbered by it next spring.

Something might be said, indeed, in favor of top-dressing grass after the hay harvest, and so getting a crop of rowen, or abundant "fall feed." But in the vicinity of Boston top-dressings are often applied so late in the year that a large proportion of the manure is apt to be washed off bodily from the frozen ground into brooks or ponds; to say nothing of the fact that what manure is left upon the land is leached by rains in such manner that many of its soluble constituents are carried away.

Composts Good for Grass.

The free use of composts, in conjunction with small quantities of appropriate chemical fertilizers for top-dressing grass fields, would probably be a considerable improvement upon the system of husbandry which prevails nowadays in New England.

For example, a Maine farmer reports that, when his grass lands get run down, he spreads upon them in the autumn a compost of marsh mud and lime at the rate of ten cart-loads to the acre, each load being equal to 35 bushels. This compost costs him 50 cents a load, and the application of it generally increases his crop from 1,500 lb. per acre to 3,000 lb. for about four years, the crop being timothy and clover of excellent quality; so that at a cost of $1.25 per acre and per year for manure, he gets ¾ of a ton of hay.

The true import of these figures may be shown by contrasting them with those of an English calculation as to the gain got by applying guano to grass. The argument was, suppose a mowing field is yielding a ton and a half of hay to the acre, and that it is top-dressed with 200 lb. of Peruvian guano in the spring so that the yield of hay is brought up to two tons, what will this extra half-ton of hay have cost? Why, very nearly $6, for there has been used $\frac{1}{10}$ of a ton of guano, and guano costs $60 the ton. Usually there would be some increase of aftermath and in the hay-crop of the next year also, because of the application of the guano, but these gains are commonly small, and the profit from them would be offset in good part by the cost of hauling and distributing the guano in the first place. It has been well said, that these prices are in the farmer's favor in case he is a buyer of hay; but if he grew hay in order to sell it, the margin for profit would be very small, especially if there be taken into the account the chances of droughty years, when guano has little or no action. But it is in years of drought that good composts often justify themselves most thoroughly.

It is noteworthy that the Maine farmer just now cited reports that, on trying a double dose of the marsh mud and lime compost, he made what he esteemed to be "a perfect failure." To use his own words, "it brought in weeds, and the grass grew so rank that for two or three years it was good for nothing"; that is to say, it was too much like young grass to be sold as merchantable hay.

Composts, when applied in the spring, at least, have one advantage over stable manure, in that they can usually be distributed more evenly upon the surface of the land. Stable manure is apt to cohere in lumps, at the best; and when it is fresh or "long," it is wellnigh impossible to distribute it very evenly. For killing moss also, which is one of the purposes of top-dressings, loamy composts have probably a decided advantage over stable manure of equal richness in fertilizing ingredients, because of their superior covering power. There are doubtless cases, especially upon clayey land and on low meadows, where mere coal ashes applied as a top-dressing to grass would serve an excellent purpose. Chip dirt, pond mud, and dust washed from roads, and even beach sand, have all been applied to grass land with advantage. As the farmers say, they keep the surface from "binding."

It is to be remembered always, that there are hay lands in England, especially near London, that have been kept in profitable grass for long terms of years by simply top-dressing them with horse manure. Loudon tells of such fields on tenacious clays that have been rendered exceedingly productive by the abundant application of stable manure hauled out from London.

Different Fertilizers favor different Grasses.

One of the most noteworthy facts with regard to the manuring of grass lands is, that very different kinds of herbage are "brought in," as the farmers say, by different kinds of manures; that is to say, one kind of grass in the mixture that occupies a field will specially prosper when the field is manured in a given way, and will tend to crowd out the other grasses. But if the field is manured in some other way, another grass, or other grasses, are liable to get the upper hand.

It has long been noticed here in New England that wood ashes when applied to grass land tend to bring in white clover, and that plaster of Paris is often an excellent manure for clover. But, as is now known, the plaster acts by setting free potash from the soil. Indeed, the celebrity of plaster as a manure depends largely upon the extensive use that was made of it at one time, a century ago, upon the clover fields of Europe. In one word, mowing fields dressed with potassic fertilizers give an abundant growth of clover rather than grass. Lime also has often been noticed to promote the growth of white clover.

This question of the influence of different classes of manures upon the growth of grass was thoroughly studied by Lawes and Gilbert some years ago, and highly interesting results were obtained by them. They found, like our own farmers, that potash increased the proportion of leguminous plants on a grass field. They found, moreover, that by far the most complex mixtures of herbage were obtained upon unmanured fields, or in general upon fields that yielded light crops; that is to say, a comparatively large number of species of plants were found in the hay from such fields, and there was no such predominance of a few species as occurred in the more bulky crops obtained from manured fields. This remark was true, not only of the grasses proper, but of weeds and other volunteer plants. As a rule, greater simplicity of herbage was coincident with any considerable increase of crop, no matter what kind of manure had been used; and there was, at the same time, a greater predominance of the grasses proper, and of some few special kinds of grasses or of clover.

Farmyard manure, beside increasing the total product, increased the amount and the proportion of the grasses proper. It diminished the variety of herbage and the proportion of leguminous plants and weeds.

Farmyard manure plus ammonium salts gave a considerably larger crop than the farmyard manure alone, and the hay contained a large proportion of grasses and weeds, but very few leguminous plants.

Mineral manures alone, whether a mixture of salts of potash, soda, or magnesia, or superphosphate of lime, increased the crop moderately, while they rather diminished the proportion of grasses, and considerably diminished the proportion of weeds. But such mineral manures greatly increased the proportion of leguminous herbage, especially that of red clover and of the meadow vetchling.

Ammonium salts alone considerably increased the yield per acre, and they increased the proportion of grasses, while they diminished the leguminous plants and weeds. In point of fact, clover and the like were wellnigh excluded when the field was manured with ammonium salts. It was noticed that the grasses tended very remarkably to run to leaf, and that the plants had comparatively little inclination to form stems or seed ; just as was the case with the field of the Maine farmer above mentioned, who overdid the dressing of the marsh mud and lime compost.

Mixtures of mineral manures and ammonium salts gave by far the largest increase of crop, and the proportion of grasses proper was much larger than was obtained in any of the other experiments. Clover and other leguminous plants were practically excluded, and the number of species of weeds and the total amount of weedy herbage were but small, though some few individual weeds grew luxuriantly. The great bulk of this large crop was made up of comparatively few species of grasses, and the development of stems and seeds was remarkable.

Sewage irrigation, when applied to mowing fields, has been found, like other active manures, to develop grasses chiefly, particularly a few kinds of free-growing grasses, such as the rough-stalked meadow-grass (Poa trivialis), couch-grass, orchard-grass (Dactylis glomerata), woolly soft grass (Holcus lanatus), and perennial ray-grass (Lolium perenne). The herbage of such meadows is very simple, and is wellnigh free from leguminous plants and weeds, excepting a few buttercups, docks, and dandelions. Since the grass of such meadows is cut when young and green, it is little matter that some of the grasses just mentioned would make rather coarse and inferior hay if left to approach maturity.

Guano on Lawns.

It has sometimes been urged that guano is specially beneficial to lawns, because it not only promotes the growth of true grasses, but may be made actually to destroy some weeds. Thus it is said that if guano is scattered in the early morning, in fair, dry weather, at the rate of 3½ lb. to the square rod, on a lawn infested with white-weed and plantains, these weeds can be eradicated; for their broad and bedewed leaves receive and hold the guano, and are poisoned by it. After the weeds are dead, and showers occur, the guano will be washed into the soil and stimulate the growth of the grass. A lawn guanoed in this way will appear brown and dirty for some little time, or until the grass has grown high enough to conceal the seared leaves. If, instead of proceeding in this way, the guano were strewn in dull, showery weather, it would excite a vigorous growth of grass without turning the field brown, and without destroying the white-weed, excepting in so far as the grass might override it.

Weedy Grass is apt to make bad Hay.

One advantage to be noted in favor of using such fertilizers as would tend to crowd out weeds is, that the true grasses dry more readily than leafier plants can. Consequently, pure grass hay is distinctly less liable to become mouldy than weedy hay. This consideration is specially important in case the hay is to be sold. Another point to be borne in mind is, that the judicious manuring of some hay fields might bring the grass into such condition that it could be mown at a different time from the unmanured fields of equal age, whereby some saving of hurry and anxiety might be made.

The crowding out of some kinds of plants by others has been dwelt upon by Mr. Darwin, who naturally looked at the matter not so much from the chemical point of view as from that of the natural historian. He found that seedlings suffer most when they germinate in ground already thickly stocked with other plants, and that, when turf which has long been mown or browsed is allowed to grow, the more vigorous plants gradually kill the less vigorous, though fully grown plants. Out of 20 species on a little plot of mown turf, three feet by four, 9 species perished from the other species being allowed to grow up freely.

Influence of Clover in Grass Fields.

In discussing the manuring of mowing fields it is important to consider the influence of the clover plants which are so often grown in conjunction with timothy. The clover, as it gradually dies out, leaves roots in the ground which undoubtedly yield a considerable amount of nutriment to the grass plants. Hence the sowing of clover seed with grass may serve to distribute in some measure the original manuring through a term of years, or to revivify the manure as it were. It is thought, moreover, that the porosity imparted to the land by the numerous roots of the clover, which leave openings and channels when they decay, is a matter of considerable practical importance, particularly upon heavy land.

Strangely enough, in view of the chemical composition of clover hay, and the great estimation in which clover is held in some of the best farming countries of the world, there are not a few farmers in New England who maintain that it is on account of the considerations just now mentioned, rather than because of any direct gain obtained from the clover hay itself, that they persist in sowing clover seed together with their grass. This opinion can hardly be correct. It is mentioned here merely to oppose it. It would seem plain that the advocates of this opinion cannot possibly esteem clover at its true worth; though it may well be true, that clover needs to be fed out green (as is usual abroad) in order to produce its best effects. It is well known, moreover, that clover should be mown tolerably early, and that it should be cured with special care in case it is to be used as hay.

Mulching of Grass Land.

The fact that mere loam has occasionally been used with success for top-dressing grass naturally suggests the inquiry in how far mulching can be made to supplement or supply the need of manure on grass land. Though manifestly open to doubt, the opinion is not uncommon, that very nearly one half the beneficial effect of stable manure, when used for top-dressing grass, may be due to its acting as a mulch.

One reason, doubtless, why young grass is more liable to be winter-killed than that which is old, is due to the fact that the old grass is protected by the dead herbage (the so-called fog) that covers the soil. It has been questioned whether it would not be well, in this sense, when land is seeded down to grass in August, to sow with the grass seed some oats very thinly, or some barley or other quick-growing plant that would be killed by the frost. The idea is that the oats, or what not, would shoot up to a height of several inches before the advent of a killing frost, and would finally fall down and cover the surface of the ground, and protect it both by acting directly as a mat and by holding snow upon the land. But in trying any such experiment as this, it is important to sow the field rather early in the season, and that there shall be moisture enough in the land to enable the oats (or other plant) to get well started before the cold weather of autumn sets in. It is hard to say just what plant would best serve this purpose. Perhaps barley would be better than oats, or perhaps vetches or peas would answer. Possibly some flowering plant, like balsams, for instance, whose seeds could readily be procured in large quantities, would do. It is a subject which intelligent farmers might well study. There would seem to be needed a rather coarse plant, that will grow rapidly in cool autumn weather until nipped by frost.

Pasturing of Mowing Fields.

Another matter intimately connected with the mulching of mowing fields is the question whether or not it is advisable to pasture cattle upon such fields in the autumn. The practice is actually a very common one in New England, although there are many farmers who condemn it utterly. It is not easy to understand the reasons of such sweeping condemnation, though it is generally admitted that timothy is ill adapted to withstand the biting of animals, and good fields of it may well be protected from them. But the trampling of cattle may often do good, especially upon light loamy soils, and as a means of destroying moss. The fact of the matter would seem to be, that on old mowing fields the practice of pasturing with moderation in early autumn may be commendable, especially where the sod is thick and the grass vigorous, while it may be hurtful on new fields of timothy, and on poor, dry exposed fields.

Anything that works to leave the ground absolutely bare is injurious, since the cold of winter tends to kill the roots. So too, the roots would be liable to die, — that is to say, they might be killed by heat, — if the fields were depastured immediately after mowing, and there can be little doubt that the presence of cattle in the fields at that season is to be deprecated. But no matter how useful the old fog may be in winter, it is evident enough that, when the spring comes round, too thick a coating of dead grass upon a mowing field is a serious annoyance. It encumbers the land, hinders the growth of the young grass, tends to smother the roots, and is a real detriment to the field. All this, beside the liability of its interfering with the scythes and rakes at the time of hay-making.

It will be noticed that careful gardeners take pains to rake off the dead grass from lawns, and grass plats, and borders about houses, every spring, in spite of the fact that there is usually but little of it. There can be little doubt that the removal of dead grass from a thick lawn is a benefit to the living grass, whatever may be the possible utility of the fog on a thin old mowing field.

The burning of dead grass by savages, all over the world, in order to get a good crop of new grass, is a fact of the same order. Mr. Olmsted, speaking of February as "a spring month in Texas," says: "The dreary burnt prairies, from repulsive black, changed at once to a vivid green, like that of young wheat. The unburnt districts, covered with the thick mat of last year's growth, were a month behind." Hence, on this account also, the argument against mowing or pasturing hay-fields in autumn must be taken with many grains of allowance.

CHAPTER XXI.

THEORY AND PRACTICE OF MAKING HAY.

The art of hay-making admits of several variations, though the principles upon which it depends are few in number and simple in appearance. Occasionally a farmer may be heard to assert that hay should be made in such wise that the product shall be "dried grass"; and the idea seems reasonable enough at first sight. There is a note of practicality in the remark, moreover, that catches the ear, and it seems to consist with the well-known fact that young grass is particularly nutritious. But the statement might easily mislead an inexperienced person, and can only be accepted as true when accompanied by explanation and qualification. It is to be presumed, indeed, that those farmers who make this remark do not mean to imply that the hay shall really resemble pasture grass, for the conceptions "hay" and "grass" are very properly separate and dissimilar in the minds of practical men. For example, if, to a farmer boasting that his hay is made so well that it is really nothing but dried grass, the question should be put, "What! do you feed your horses on rowen?" he would probably find himself somewhat puzzled for an answer. For it is notorious that, when horses are fed upon soft succulent food, such as grass, or vegetables, or rowen hay, their muscles become "soft." In reality, the flesh produced by such food is, comparatively speaking, watery. Animals perspire easily when thus fed, and are not fit for hard work. Hence the popular conviction that horses, in particular, need "ripe" or mature hay. This feeling was well expressed by a farm hand, who, on being directed to feed out a lot of rowen hay to some idle horses, remarked that it would be just as well to give them curled hair.

The truth of the matter is, that, in order to get good hay, the grass should be mown at the time when it is in the condition best fitted for the purpose to which it is to be put; and the crop should then be secured with as little waste as possible. Moreover, in case the hay is to be sold, it should be made in such manner that it may present a fine appearance.

Sources of Waste in Hay-making.

There are several well-defined sources of waste in hay-making. First, the risk of washing by rain after the grass has been cut, whereby starch, dextrin, and other soluble matters, including a good part of the ash ingredients, are dissolved and removed. Secondly, the development of fungi in damp hay, both in hay that has been wet by rain and in that from which the natural juices have not been properly dried off. This question of fungi in damaged hay and other fodders is doubtless a very important one, since some of the fungi, or at the least the altered materials upon which they are found, are distinctly hurtful to animals. Several instances have been recorded where mouldy oats fed out to horses have caused the death of the animals; and it is a popular belief that many diseases of cattle are occasioned by the consumption of hay that has been partially rotted by exposure to dampness. Such hay is thought to be always injurious to all kinds of animals. Several farmers have urged that one great advantage in using hay caps is to be found in the fact that they hinder the development of fungi.

Unfortunately, very little seems to be known as yet concerning these harmful fungi. It would be well to know certainly whether hay or oats damaged by them could, in all cases, be made harmless by steaming. An impression prevails that they could in this way be rendered completely innocuous. The advocates of cooked fodder have been accustomed to urge that the steaming of damaged hay, to which a little bran or meal has been added, will make it palatable to cattle, and that the animals prosper on such a diet. There can be no doubt that, as a general rule, it is safer to feed damaged hay after cooking than before.

Salting of Hay.

The real justification of the common practice of salting hay when it is pitched into the mow or stack, or of scattering slaked lime upon it at that time, is undoubtedly to be found in the power of the salt and the lime to check the growth of fungi. The salt and the lime both work to check fermentation, and to prevent moulding, and the use of them is undoubtedly commendable in special cases, as when partially cured hay has to be stored in bad weather, or as in the short days of autumn, when rowen cannot be properly dried in the fields. It is an interesting fact, that in the interior of the country, — that is to say, far from the sea-coast, — where animals rarely get all the salt they would like, cattle often prefer hay that has been salted, under the conditions just now described, to the best hay that has been made perfectly, according to the usual methods. Many people have argued from this circumstance, that all hay should be slightly salted, and the practice of doing so has become general in many localities. It is no uncommon thing to see New England farmers scattering a peck of salt to the ton of hay, as the latter is thrown upon the mow, no matter how good the hay may be. In so far as the appetites of the animals may be increased, the putting of salt or lime upon well-cured hay may be well enough, and for saving damp or weedy hay both these additions have undoubted merit; but there is really no need of them on hay that has been well dried and properly housed.

In case dry straw, as well as salt, can be mixed with the damp hay, layer by layer, when the latter is to be stacked out of doors, as is usually done in Europe, it is said that still better results are obtained than can be got by the use of salt alone. The straw imbibes the moisture from the damp hay, and much of its flavor also, so that cattle will readily eat the entire contents of such a stack, — the straw as well as the hay.

Hay that is admixed with some kinds of weeds stands in special need of being salted. In case, for example, a field infested with white-weed or buttercups were mown early in the season, to prevent these weeds from seeding, it might not be found easy to dry the young grass and the succulent herbs completely. Hence it is well to salt such hay freely as it is stored in the mow. It may be said, in passing, that weedy hay such as this is highly nutritious, and excellent for milch cows.

The preservative action of salt in hay-mows is well illustrated by the fact, that, on the sea-coast of New England, it is easy to keep watermelons that have ripened in September fresh and sound until December, by simply packing them away in a cool barn in "salt hay," i. e. hay made from grass grown upon salt marshes. Of late years, large quantities of this salt-marsh hay have been used for packing bananas also, that are transported into the interior of the country.

Crumbling of Leaves and Dropping of Seeds.

Beside the risk of loss from washing, and from the development of fungi, there is the waste of delicate leaves when hay that has been allowed to become very dry and crisp is handled; and this loss of material, due to the crumbling of leaves, is all the more important, because the delicate friable leaves are excellent fodder, and constitute, perhaps, the very most valuable parts of the plants. In the case of clover hay, in particular, the loss by friction is often of considerable importance, and it is always well, when harvesting hay at a very dry time, to take care that it does not become too crisp before raking, cocking, and housing it.

Then again, if grass be mown when it is fully ripe, much nutriment will be lost in the form of seeds. Timothy in particular yields many seeds which are highly charged with nutritive matters. But many of these seeds shake out from the dry husks; mice are fond of them, and not a few escape mastication and digestion when the hay is eaten by animals. Hence a tendency on the part of some people to jump at the not wholly justifiable conclusion, that grasses may really yield more and better hay when mown in blossom, than if left to become more mature.

The Aroma of Hay.

The loss of aroma from hay during the process of making is a point of some importance. All those volatile matters escaping from new-mown hay, which are so agreeable to our sense of smell, are of course lost from the crop, and this loss might be serious if it were allowed to go on indefinitely. This aroma seems to be agreeable to cattle, in that the presence of it makes the hay more palatable. Other things being equal, sweet-smelling hay will be readily salable. Hence those processes of curing hay which tend to retain the aroma are in so far commendable.

It should be understood, that the aromatic matters which escape during the making of hay do not volatilize of themselves to any great extent, in the sense that alcohol, ether, or water would evaporate from an open dish. They are in reality lifted, as it were, and transported by the vapor of water as it escapes from the grass. Hence one great harm that ensues when partially cured hay is wet with rain, or fog, or dew. By the evaporation of this new and extraneous water, just so much more of the aromatic matters are carried off. A familiar example of this transporting power of aqueous vapor is seen in the freshness and sweetness of the early summer morning. When the sun begins to dissipate the dew that has fallen during the night upon the surfaces of sweet-smelling flowers and leaves, there is a movement of perfumes in the air such as seldom occurs at noonday. It is to avoid this lifting power of dew, as well as to guard against loss of heat by radiation and from contact with the cold night air, that half-cured hay is raked up before night into windrows or cocks, in such manner that no more than a comparatively small surface of it shall be directly exposed to the weather. Here is one reason among many why hay caps are used by careful farmers.

Chemically considered, the aromatic matters are probably essential oils, perhaps of no direct value whatsoever as food, excepting in so far as they give flavor to the hay, to make it palatable, and act after the manner of relishes to help digestion. In England the farmers often buy a condiment sold as "hay spice," which is warranted to improve all hay, and particularly to give to rough coarse hay, or that which has been damaged, an attractive flavor and an aromatic odor.

Fading of Hay.

The color and the appearance of hay need to be considered, particularly when the hay is to be sold as such. For the sake of its appearance merely, it may sometimes be desirable to dry grass gradually, to expose it to direct sunlight as little as may be practicable, and in general to proceed in such wise that the hay shall be of handsome green color, and of the same bright tint throughout. If new-mown grass were left to lie too long in hot sunlight, without turning, part of it would become brown and withered, while the rest would not, and it would then be wellnigh impossible to get the best-looking hay. Hence it is held to be bad practice to scorch hay, or, in other words, to leave it too long unturned in the hot sun.

The change of color by the action of sunlight is a mere matter of fading, just as a colored cloth would fade when exposed to sunlight; and it should be borne in mind that nothing fades clothes more rapidly than alternate rain and sun. In the old methods of bleaching cotton or linen, the practice was to spread the cloths upon a grass field, to keep them moistened, and to turn them frequently in order to promote the chemical changes upon which bleaching depends. It is important, therefore, to avoid dew and rain, as well as too much sunlight, when the intention is to get green-colored hay.

From chemical considerations, it is plain that these influences which work to destroy the color of grass and to remove the aromatic matters would tend to destroy some of the nutritive constituents also. Hence it would appear that green-colored and sweet-smelling hay is really the best possible hay, and that these attributes may well be regarded as indicating the highest standard of excellence.

The liability of organic matters to undergo change in sunlight is well illustrated by a case somewhat analogous to that of hay; the case, namely, where herbs are cured for medicinal uses. All are agreed that herbs are best cured in the shade, and that strong sunlight should not be allowed to fall upon them. But if the sun's light and heat can bring about changes in the medicinal principles of herbs, it is fair to infer that the nutritive constituents of other vegetables are liable to suffer in like manner. This tenet that direct sunlight should be avoided consists very well with the dictum that hay should be simply dried grass, and would seem to be reasonable enough in itself, if only it were possible for the farmer to control the weather in haying time so that he could cure the crop at his leisure.

Curing of Hay in Cocks.

It is in part, perhaps, with the view of retaining the aroma and fine appearance of hay, that many persons have urged that it is best not to spread or turn hay in the field any more than is absolutely necessary, but to cure the mown grass in swaths, windrows, and cocks, at least for the most part. There is, however, another and a much more important reason than this, which has often been urged in favor of curing grass in heaps, as will be explained on a subsequent page.

Fermentation means Waste.

Beside the loss of aroma, and the change of color, and the comparatively insignificant alterations due to excessive light, it is important to recognize that considerable losses of foddering materials must necessarily occur whenever and wherever hay undergoes fermentation, or active chemical change, during the process of curing. Hence the importance of avoiding all extraneous moisture, as of rain or dew, and of not leaving accumulations of grass or half-cured hay to themselves long enough for fermentation to occur.

It is on this account, as well as because of leaching, that the repeated wetting and drying of hay during the making of it is thought to be specially detrimental. In times of frequent showers it is held to be better, as a general rule, to let half-cured hay alone, than to run the risk of meddling with it. If it is in cocks or windrows, the custom is to let it remain there untouched as long as the weather holds foul or uncertain, in spite of the imminent danger of its moulding in the heaps. So, too, when grass is mown wet, and is then rained upon, or when rain sets in before the swaths have been spread, it is not customary to disturb the grass until the weather becomes fair. Fresh-cut grass "keeps" fresh — much as meat would keep — fairly well in cool, rainy weather, though there can hardly fail to be a considerable loss of soluble matters that are dissolved and washed out as such.

It is because of the risk of rain, and the deteriorations which are apt to be caused by wetting, that many farmers like to dry their hay as rapidly as possible. The common feeling was well expressed by one of them, who, after listening to a long debate on the question how to cure hay, remarked that, in his opinion, the main point was to get it into the barn as quickly as possible after the grass had been cut.

In consonance with the efforts for rapid drying, many farmers now throw their half-cured hay at night into loose bunches with the horse-rake, or merely into large windrows, instead of spending time in making well-formed cocks. Next day, the bunches or windrows may be rolled over, to expose their under side to sun and air.

Importance of allowing Mown Grass to Sweat.

Somewhat in opposition to the plan of making hay rapidly, many good farmers maintain that, in order to cure hay thoroughly well, the grass should be allowed to "sweat" freely while making. It is really for this purpose that the system of hay-making which depends upon the slow drying of grass in swaths, windrows, and cocks, is practised. The idea is, that, when mown grass is left in small heaps, the leaves will continue to transpire water, very much as they would do if the grass were still standing uncut.

So long as the grass remains alive, water will be exhaled from the pores upon the surfaces of the leaves, and water will continually be pumped out from the stalks in a thoroughly natural way, much as if the grass had not been mown. Whereas, if newly cut grass were immediately spread in hot sunshine, the leaves would speedily be scorched to such an extent that circulation of moisture within them would cease, and transpiration of moisture from their pores become impossible. After the physiological appliances for removing water have been destroyed in this way, the moisture in the stalks can only escape by way of simple evaporation, and, as that process is necessarily slow, there would be danger of carrying to the mow hay that really contained a large amount of water in its stalks, although it might seem to be tolerably dry, to judge merely by the crispiness of the leaves. In this point of view, the ideal plan of hay-making would be to spread the mown grass out thin, and let it wilt "just enough," but no more than enough, and then to put it into windrows or little cocks, so that the leaves might continue to draw moisture from the stems. Many farmers assert that hay which has been cured in this way, by being allowed to stand in the cocks two or three days, always keeps better than that made by spreading the grass.

Naturally enough, in trying to make hay in this way, it often happens that more or less fermentation will occur; and many farmers appear, indeed, to confound this accidental fermentation with the true sweating, and to regard it as an essential feature of the system of making hay in cocks. At all events, there are many practical men who maintain that hay which has undergone a touch of fermentation during the sweating process is sweeter and more palatable than hay which has been merely dried. Some of them have even gone so far as to question the utility of drying grass by artificial heat, supposing it more practicable to do so with economy, as the English have striven to do of late years. But the proper argument in this case is clearly, that, not fermentation, but a true sweating out of moisture from the stalks, had better precede the process of artificial drying, in order to get really good hay.

As practised by extremists, the system of sweating is somewhat as follows. Hand-mown grass is left to lie in swaths without spreading until it is considerably wilted, or, in case the crop is very heavy, the grass is spread somewhat. While still warm, the wilted grass is raked up into cocks large enough to promote gentle "sweating," but not so large that rapid or violent fermentation may be developed, for that would be not a little dangerous in case the weather should happen to become foul. After the sweating, the rule is to open the cocks into beds, and to carry the hay to the barn as soon as it has become dry enough.

No doubt excellent hay can be made by this method of so-called sweating, in which more or less fermentation is allowed to occur; and it is important for beginners to grasp the conception, for the weather may often force the farmer to resort to this process, or to some modification of it.

The importance of sweating, properly so called, i. e. of allowing water to transpire from the leaves of mown grass until the stalks have been sucked somewhat dry, is seen most distinctly in the case of clover, which, as is generally recognized, needs to be cured more carefully than grass. If the attempt were made, in our dry American climate, to dry clover rapidly by direct exposure to sunshine, the leaves would become too crisp and brittle to be handled long before the succulent stalks were dry. Hence the importance of so handling the green clover that the moisture of the stalks may have time and opportunity to transpire from the leaves. The same reasoning will apply, of course, to any specially succulent crop of grass, such as a heavy growth of timothy cut young, millet, or the like, more strongly than it would to the finer kinds of grasses.

Some writers have held, and apparently with good reason, that the sweating and fermenting process is specially applicable for curing coarse and rough kinds of grasses. Not indeed the so-called sedges which make up the bulk of the bog-meadow hay in Massachusetts, for the sedges will bear only a very moderate amount of fermentation, and are readily spoiled. But such grasses as the large Glyceria and Agrostis, the great Festuca gigantea, and the reed-canary or ribbon grass (Phalaris), which grows abundantly on the borders of brooks, and yields a considerable burden of coarse, rough hay. Probably such grasses as these might well be put into small cocks while they were still rather green and damp, and there be allowed to sweat and ferment a little.

It would seem to be plain that the roughness and coarseness of the grass might be diminished by a small touch of fermentation, and that the hay might thereby be made more palatable to cattle.

But it is questionable whether there is any truth in the idea, which many people have held, that the woody fibre in coarse hay is changed and improved chemically by the fermentation, so that it is not only more palatable to stock, but actually more nutritious. In general, it may be said that the sweating process is a valuable resource for dealing with succulent hay, as well as for treating any kind of hay when the weather will not permit it to be made in the ordinary manner. But too much stress must not be laid on the necessity of actual fermentation, for there is really no need of it.

Several good Ways of making Hay.

It is well to recognize the facts that very good hay may be made by several different methods, and that the whole subject of haymaking is so dependent upon weather and climate that it is practically impossible to lay down precise rules of conduct. In the rainy uplands of Bavaria the grass is dried upon little racks, such as are used for curing bean vines in New England; i. e. the hay is piled upon little posts with cross pegs, so that a large surface of it shall be exposed to the air. The same practice is said to prevail in Switzerland, and in many other mountainous districts in Europe, where the ordinary system of making hay on the surface of the ground would be impracticable, because of wellnigh incessant small showers that keep the land wet. In Loudon's Encyclopædia of Agriculture, there are figures of these racks as used in Sweden, and on the islands at the north of Scotland.

"Heating" of Half-cured Hay.

The warmth developed in cocks of hay as soon as fermentation begins, and which is really due to chemical action, must not be confounded with the natural warmth which is retained by the cocks and windrows into which hay that is being made by the ordinary processes is raked every afternoon. One chief object of these windrows and cocks is, that they serve to hold a good part of the warmth that is raked up, so to speak, in the half-cured hay. They hinder the hay from cooling off during the night, so that it shall be all ready to begin to dry the moment it is spread in the morning.

Of course, if the cocks of half-dried hay are left too long unopened they will ferment, i. e. they will "heat." In a word, chemical changes will set in, and heat will be developed. It is not easy indeed to distinguish very clearly between the natural warmth which is raked up in the hay, and the heat due to chemical changes which succeeds it, for the two kinds of heat shade into one another insensibly, and it will often happen that, long before the natural warmth has exhaled from the cocks, the chemical warmth will begin to be developed. It is easy enough however, to conceive of the two sources of heat, and to hold the conceptions apart.

Utility of Hay Caps.

One advantage gained by the use of hay caps, as applied to protect the cocks during the night, is that they hold in the raked up warmth, and keep the hay from cooling off during the night. Thus it happens that the hay not only improves a little as to dryness during the night, but is all ready to dry rapidly when the cocks are again exposed to air and sunshine, on being opened in the morning. All this as a normal or constant benefit, let alone the advantages that are derived from the caps in case light rains, or even heavy rains, should fall before the cocks are again opened. The caps keep dew from settling upon the hay, moreover, and thus prevent the loss of aromatic matters that would occur if dew were to dry off from the hay.

There can be no question as to the very great merit of hay caps when properly used. They are nothing but square pieces of stout cotton cloth, which are thrown over the cocks at nightfall. In order that the cloth may be kept in place, it has wooden pegs attached to each of its four corners; and these pegs may either be driven into the ground, or pushed into the cock itself, according as time presses or not, and according to the size of the cock and the state of the weather.

Dew brings Spores.

With regard to the exclusion of dew, it is not alone its power to carry off aroma that should be considered. When dew "falls," it must tend to carry with it any particles of solid matter that may happen to be in the air from which it is deposited, and in this way the spores of fungi, such as would cause the hay to mould, are put upon it. Several naturalists have proved that this result does actually occur, by hanging glass jars full of ice in the fields, collecting the liquid which is deposited upon them, and examining it with the microscope. There can be no question that many of the organisms thus deposited in dew are liable to produce hurtful decompositions of the hay, especially in case it should remain damp, or become damp, and it is plain that the fewer of these organisms get into the hay, the better it will be for the farmer. It might readily happen, indeed, that many of the spores that fall upon dead grass, i. e. upon half-cured hay, would take root, as it were, in that situation, and grow at once, although their predecessors that had been falling continually upon the living grass might not have found there any fit abiding-place.

Thirty odd years ago, when hay caps first came into use, they were hailed with acclamation; but they soon received a very severe check, from which they have never recovered. The price of cotton, namely, was so high during the war of the Rebellion that few people could afford either to buy it or to keep it for ordinary purposes. Hay caps are unpopular withal among hired laborers, who slight them and deprecate their use.

In reality they cause very little extra labor or trouble, provided the ropes to which the pegs are attached are thick enough and stiff enough not to snarl. In spite of all drawbacks, it is unquestionably true that hay caps do quickly and constantly repay their cost and the trouble of using them, especially on farms where hay is made to be sold. Eventually, no doubt, hay caps will be prepared from cloth which has been tanned, as sails are in damp climates, or otherwise treated with chemicals, so that it shall be preserved from deterioration through mildew or decay.

Brown Hay.

Beside the plan of having hay undergo in the making some slight fermentation, in connection with the true sweating, there is another much more emphatic conception put in practice in the process of making brown hay, so called. This is a process which is dependent upon decompositions that are a good deal more than incipient; but which has nevertheless found favor in many districts, especially in countries where the weather can never be depended upon for making hay by the usual process.

In making brown hay, most of the water of the grass is driven off by the heat of fermentation, only about a third of the original moisture being dried off by sun and air in the first place. Far from seeking to bring the hay into contact with the air, the chief care in this process is to exclude air from the hay. For making brown hay, grass that has been wilted to such an extent that the leaves have shrivelled, although the stalks are still plump, is heaped up either in rather large masses, or in smaller heaps that have been trodden in such wise that the air shall be wellnigh or altogether excluded from the interior of the heap. Under these conditions, fermentation soon sets in, and proceeds with a good degree of regularity. In the course of it the heap becomes very hot, often as hot as the temperature of boiling water; the hay takes on a deep brown color, and gives off an odor of caramel or burnt sugar.

In point of fact, some of the constituents of the hay undergo the well-known fermentations which chemists distinguish as the "alcoholic," the "lactic," and the "butyric"; in other words, a considerable part of the carbohydrates in the hay, notably the sugar and the dextrin, are changed to alcohol, carbonic acid, and lactic and butyric acids. Of course, a considerable proportion of the carbohydrates are destroyed by these changes. The large amount of heat that is developed comes from the destruction of these things. Some persons have thought that enough heat is developed to kill the germs of hurtful fungi which may have existed upon the grass, and that the hay is thus protected from mouldiness and from putrefaction. More probably it is the copious evolution of carbonic acid during the fermentation, and the lactic acid formed, which hinder the development of the microdemes that cause putrefaction.

Brown hay that has been properly prepared is greedily eaten by cattle, and readily digested and utilized by them. Since the fermentation destroys a larger proportion of the carbohydrates of the grass than of the albuminoids, it follows that brown hay must be a somewhat more highly nitrogenized food than ordinary green hay. This may at one time have been a reason for making brown hay that can no longer have so much force as formerly. At a time when the farmer could not readily procure nitrogenized foods by purchase, he might have have had an incentive for getting such food in the form of brown hay. But this excuse would no longer be a valid one in the face of abundant supplies of bran, oil-cake, and cottonseed meal, that are obtainable in every market nowadays.

There is a certain analogy between brown hay and black tea. Black tea is made from the same kinds of leaves as green tea, and the leaves are plucked at the same stage of their growth. But for making black tea the leaves are fermented in heaps before drying them, while for green tea the leaves are dried directly.

The real justification for making brown hay is, that the farmer becomes independent of climate, and that even very weedy grass may be saved in this way in the worst of seasons. Much labor is required, of course, in raking up and carrying the heavy green grass. The loss of dry organic matter in making brown hay is large. Probably it is never less than 14 or 15% of that originally contained in the grass, and it is frequently much larger than this.

Instead of making brown hay, grass may be trodden into pits and converted into ensilage, much in the same way as is done with fodder corn. This process also is commended for weedy hay and for rainy regions, in case a long-continued spell of wet weather puts off the hay harvest until there is a risk that the grass may get over ripe before any chance shall occur for making it into hay by the ordinary methods of drying. For saving rowen also, in the short days of late autumn, silos may serve a highly useful purpose, especially if the weather happens to be wholly unfit for hay-making.

Dryness of Hay when stored.

Practical men attach much importance to the putting of hay in the barn at a time when it is in proper condition in respect to dryness; i. e. at a moment when it is neither too damp nor yet over dry. It is held as a tenet of faith in New England, that for making bright, sweet, and salable hay it is best to dry the grass in the field no more than is necessary for the perfect preservation of the hay in the mow. It seems to be pretty well agreed, that hay keeps best when it is put in the mow in such a condition of dryness, or rather of moistness, that, on being trodden, it will settle down upon itself into a firm, compact mass; it being understood of course that the barn is airy and well ventilated. It is said that hay which has been over dried in the field will not settle down in this way, particularly if it should happen to be coarse, but will remain comparatively loose and porous, so that air has much readier access than is desirable to the interior of the heap. So, too, the carbonic acid, which is always generated in considerable quantities in mows or stacks of new hay, will escape, perhaps more readily than might be for the best.

It would appear that there are two dangers to be guarded against in storing hay: 1st. The possibility of too pronounced chemical action, such as would occur in case there was too much moisture in the hay when it was put in the mow. In that event the hay would "heat" unduly, and become mouldy. 2d. Such undue expulsion of the original moisture as would waste the aromatic principles and prevent the hay from ripening properly in the mow. It is a common opinion that animals, horses in particular, will eat hay made from inferior kinds of grasses much more readily in the autumn, when it is comparatively speaking fresh, than they will in winter and spring, after it has been longer in store. As the farmers say, such hay is fairly good fodder before the sap has all gone out of it. One explanation of the use of salt in hay-making is, that it permits the hay to be stored in a duly moist condition, — moister than one might care to store it if no salt were at hand. It would appear, in general, that while hay that is fit to be housed should not feel damp to the hand, it should not by any means be dry enough to be brittle, so that it would break easily on being bent.

Some New England farmers like to pile a quantity of poor bog-meadow (sedge) hay upon their mows of English hay, with the idea that the whole of the English hay shall be compressed, and the upper surface of it be protected from air and from the condensation of moisture that is generated below during the sweating process. In this way, the English hay is made to sweat properly, even to its uppermost layer, and the warmth of this mild fermentation, extending even to the top of the hay, expels the moisture which might otherwise condense there. In hay thus covered and compressed, the carbonic acid resulting from the fermentation would be apt to saturate the good hay completely, and hinder the fermentation from passing into an injurious form.

Old and New Ways of Mowing.

Formerly, in the days of scythes, the ordinary method of dealing with the not very heavy crops of grass in New England was to mow very early in the morning, to spread the mown grass as soon as the dew had dried off the ground, to turn it on occasion, and to rake it up and cock it in the afternoon before dew had begun to fall. Next day, the cocks were opened into beds as soon as the ground had become dry and warm, the beds were turned at eleven o'clock or so, and the hay was carried to the barn before it had become dry enough to crumble.

Many farmers dwell on the importance of housing hay tolerably early in the afternoon, while the hay is still warm with the sun's heat, so that the process of curing may go forward in the mow without interruption.

In contrast with the foregoing plan, the work is often arranged nowadays so that fresh-cut grass, and not the nearly cured hay, shall be left in the field over night. That is to say, the grass is cut with the mowing-machine at five or six o'clock in the afternoon, or earlier, if much hay is to be cut, and left over night where it falls. Next day, by stirring it freely, it will be ready to house in the after-

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noon if the weather is fair. The argument is, that grass thus cut rests upon warm ground during the night, and gets the first rays of the sun in the morning, whereby dew is quickly dried off, and transpiration of moisture from the leaves is promoted. Having become somewhat wilted in this way, the grass dries rapidly in the heat of midday. Moreover, in case foul weather should set in during the night, the grass, being still green, would suffer little harm. By this plan, again, some labor in cocking and capping is saved.

Formerly, when scythes were used altogether, there was an advantage in working very early in the morning, since it was easier to mow when the grass was plump with moisture and wet with dew; but there is said to be no such strong incentive to go out early with the machine. Indeed, it is one advantage to be credited to the machine, that it gives the farmer opportunity to avoid dew altogether, and to keep clear from the injurious lifting power of that agent. Instead, therefore, of proceeding in the manner first described, the plan is modified nowadays so that the grass is cut with the machine after the dew is well off it in the morning, then turned repeatedly with a horse tedder and put into the barn before night, if the day is a good hay-day.

If everything were propitious, the work would be arranged somewhat as follows. Mow with the machine until the middle of the forenoon, then change the horses from the machine to a tedder, and go over the field three or four times therewith. If the day is fair, the hay may be housed late in the afternoon. The enormous gain in thus using machinery is palpable. Fair weather may be utilized to the utmost. Whenever there is a good hay day, it can be put to thoroughly profitable use. The making of hay in one day in this way is common enough in Massachusetts, excepting immediately upon the sea-coast, but it is none the less true that excellent weather and a not too heavy stand of grass are essential conditions to success, unless indeed the grass is overripe when cut. If the crop is heavy, or the weather damp, a second day will be needed. Both the kind of grass and the condition of ripeness at which it is cut are very important considerations. Young grass dries slowly, while that which is mature needs to be cured but little. If there is clover among the grass, the process of drying will need to be somewhat different from that proper for grass alone.

There are, in short, two or three good systematic ways of making hay, one or the other of which is to be preferred, according to circumstances. 1st. The grass may be mown in the morning, turned often to dry it as rapidly as possible, and housed before night. Or, 2d. The grass may be cut in the morning, turned at midday, and put into cocks before the dew falls and while the hay is still warm. Next day the cocks will be opened into beds, which will be turned in due course. In good weather the hay will be ready for the barn early in the afternoon. Or, 3d. Mow in the late afternoon, and spread and house next day, as was said.

Composition of Grass at different Stages of Growth.

The chemical history of the growth of several of the cultivated grasses has been studied by Professor Collier, of the U. S. Department of Agriculture, as will appear from the following tables. For the sake of closer comparison, the hay is supposed to have been completely dried, at 212° F., in each instance. The samples were of timothy (Phleum pratense), taken from old fields,

AT WASHINGTON, D. C.

	Spike invisible.	Spike visible.	Before Bloom.	Early Blossom.	Full Bloom.	Early Seed.
Ash	8.68	6.41	9.82	6.04	5.66	10.53
Nitrogenous matters (equal N × 6.25)	12.54	11.90	10.33	10.20	9.90	12.10
Carbohydrates	54.31	57.26	54.19	57.21	58.93	50.07
Crude cellulose	19.91	21.03	22.03	22.70	21.93	22.90
Fat, &c.	4.56	3.40	3.63	3.85	3.58	3.40
	100.00	100.00	100.00	100.00	100.00	100.00
Nitrogen	2.01	1.86	1.65	1.63	1.58	1.93
Non-albuminoid nitrogen	0.70	0.55	0.36	0.30	0.38	0.51
Per cent of the nitrogen that was in the form of non-albuminoid matters	35.00	29.50	21.80	18.40	24.00	26.40
Water in the green grass	70.70	71.90	67.50	64.90	67.20	67.80

IN NEW HAMPSHIRE.*

	Spike invisible.	Spike visible.	In Bloom.	After Blossom.	Early Seed.
Ash	5.19	4.73	4.57	3.88	3.20
Nitrogenous matters (= N × 6.25)	9.66	9.61	5.79	5.25	5.41
Carbohydrates	57.09	56.10	57.16	58.72	62.50
Crude cellulose	23.46	25.34	28.28	28.92	26.03
Fat, &c.	4.60	4.22	4.20	3.23	2.70
	100.00	100.00	100.00	100.00	100.00
Nitrogen	1.55	1.54	0.93	0.84	0.87
Non-albuminoid nitrogen	0.30	0.45	0.10	0.15	0.18
Per cent of the nitrogen in form of non-albuminoid matters	19.40	29.20	10.80	17.90	20.70

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* The sample from New Hampshire was grown upon a much poorer soil than that from Washington, which had been liberally manured. The increase of the nitrogenous constituents in the Washington hay late in life, recalls the similar fact in the case of Arendt's well-fed oat plants.

Other analyses of timothy, subsequently reported by Mr. C. Richardson of the U. S. Department of Agriculture are given in the following table.

	Specimens from Washington, 1st Year's Growth.			
	Head out, 49 cm. high.	In Bloom, 76 cm.	After Bloom, 65 cm.	After Bloom, 75 cm.
Ash	8.58	7.16	6.52	5.63
Nitrogenous matters (= N × 6.25)	14.15	10.99	8.74	8.18
Carbohydrates	47.22	50.03	51.79	55.39
Crude cellulose	23.95	27.35	28.26	27.08
Fat, &c.	6.10	4.47	4.69	3.72
Nitrogen	2.26	1.75	1.40	1.27
Non-albuminoid nitrogen	0.39	0.51	0.25	0.15
Per cent of the nitrogen in form of non-albuminoid matters	17.30	29.10	17.90	11.30
Water in the green grass	78.56	66.75	56.63	58.86

	Specimens from Indiana.					From Maryland.[*]
	Head not out.	Before Bloom.	In Bloom.	After Bloom.	Early Seed.	In Bloom.
Ash	7.94	7.64	7.05	6.63	5.95	4.93
Nitrogenous matters (= N × 6.25)	10.97	7.30	5.52	5.57	4.84	7.69
Carbohydrates	49.98	52.64	52.99	53.93	60.77	52.83
Crude cellulose	29.19	29.65	32.26	31.32	24.70	30.43
Fat, &c.	1.97	2.27	2.18	2.55	3.74	4.22
Nitrogen	1.75	1.25	0.88	0.89	0.78	1.23
Non-albuminoid nitrogen	0.18	0.28	0.00	0.03	0.00	0.15
Per cent of the nitrogen in form of non-albuminoid matters	10.30	22.40	0.00	3.60	0.00	12.20
Water in the green grass	70.00	67.50	64.50	56.30	53.00	64.00

It will be noticed that these analyses give comparisons of grasses which had been grown under varied conditions, and that they illustrate the familiar truth that plants grown on poor land are apt to contain less nitrogen than those grown upon soils that have been richly manured. It is also noteworthy, that, while the amount of nitrogen in the samples of hay from New Hampshire and Maryland was much lower than in the hay from the highly manured land at Washington, it was lower still in the hay that came from Indiana. That this Indiana hay had in general been poorly nourished seems evident from the high percentage of cellulose and the low percentage of fat which were contained in it. The Indiana hay differed, moreover, from the other samples, in that there was no non-albuminoid matter in it when it was mature. All the nitrogenous constituents in that grass were converted into albuminoids during the process of ripening.

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[*] Grown upon a poor, old field.

The results of these analyses enforce anew the lesson as to the very great influence which is exerted by soil and climate upon the development of crops, particularly as to the times and stages at which their constituents may undergo change. Some other examples of analyses of grasses, selected from Prof. Collier's reports, are given in the following tables.

RED-TOP (AGROSTIS VULGARIS) GROWN AT WASHINGTON, D. C.

	From well-manured Land.							From a different Locality and poorer Soil.	
	Panicle not out.	Panicle out, but closed.	Early Bloom.	Full Bloom.	Seed in Milk.	Seed hard.	Seed matured.	Panicle Spreading.	Early Bloom.
Ash	8.19	7.34	7.55	7.27	6.60	6.74	5 30	8.41	5 84
Nitrogenous matters (N × 6.25)	13.19	13.61	12.73	11.02	10.44	9.47	8.89	9.81	9.95
Carbohydrates .	53 88	54.13	54.46	56.82	60.02	58.88	61.32	57.41	58.49
Crude cellulose .	20.97	20.87	21.64	22.02	19.43	20 66	21.75	20.49	20.42
Fat, &c. . . .	3.77	4.05	3.62	2.87	3.51	4.25	2.74	3.88	5 30
Nitrogen . . .	2.11	2.18	2.04	1.76	1.67	1.52	1.42	1 57	1.59
Non-albuminoid nitrogen . .	0.82	0.80	0.54	0 53	0.36	0.18	0.09	0.28	0.32
Per cent of the nitrogen in form of non-albuminoid matters	38.90	36.70	26.40	30.10	21.60	11.80	6.30	17.80	20.10
Water in the green grass	67.80	68.10	70.10	61.40	52.30	51.50	57.00	68.20	58.80

ORCHARD GRASS (DACTYLIS GLOMERATA), FROM WASHINGTON, D. C., GOOD SOIL.

					Later Growth, near end of June.		
	Panicle not out.	Panicle closed.	Full Bloom.	After Bloom.	In Blossom.	Late Bloom.	Seed nearly ripe.
Ash	10.29	8.26	8.07	9.01	8.64	6.00	6.73
Nitrogenous matters (N × 6.25)	15.97	10.39	9.53	8.25	12.51	8.62	7.30
Carbohydrates	50.86	55.04	53.76	52.65	50.20	57 34	57 54
Crude cellulose	18.76	23 18	25.40	27.26	24 67	24 42	25.09
Fat, &c.	4.12	3 13	3.24	2.83	3.98	3.62	3.34
Nitrogen	2.49	1.63	1.53	1.32	1.99	1.38	1.16
Non albuminoid nitrogen . .	1.01	0.30	0.16	0.33	0.77	0.42	0.45
Per cent of the nitrogen in the form of non-albuminoid matters .	40 60	18.40	10.50	25 00	38.70	30.40	38.80
Water in the green grass . . .	78.80	79.80	77.80	73.50	66.90	60.20	62.80

The regularity of the increase of some of the constituents of the orchard grass, and of the decrease of others, was very marked, both in early and in late growth. Non-albuminoid nitrogenous matters tended to disappear in middle life, and to reappear afterwards during the ripening of the seed. They are subject to great and evidently rapid changes at the time when the grass is in blossom, as will appear from the following table of other analyses, by Collier, of orchard grass from various localities, which is given more particularly to illustrate the influence which soil and climate may have upon chemical composition.

Orchard Grass in Early Bloom.

Locality.	Ash.	Nitrog. Matters (N × 6.25).	Carbohy.	Cell.	Fat, &c.	Nitrogen.	Non-alb. N.	% of N. in form of Non-alb.
Dist. Columbia	8.64	12.51	50.20	24.67	3.98	1.99	0.77	38.7
North Carolina	8.90	10.29	52.16	24.97	3.68	1.61	0.63	39.1
Full Bloom.								
North Carolina	7.42	9.91	56.03	23.08	3.56	1.58	0.30	19.0
Dist. Columbia	8.07	9.53	53.76	25.40	3.24	1.53	0.16	10.5
Maine . . .	8.02	8.74	54.80	26.05	3.39	1.40	0.36	25.7
Dist. Columbia	6.00	8.62	57.34	24.42	3.62	1.38	0.42	30.4
Pennsylvania .	6.33	8.56	54.94	27.51	2.66	1.37	0.51	37.2
New Hampshire	8.44	8.41	54.75	24.91	3.49	1.35	0.42	30.9
Average of early bloom . .	8.77	11.40	51.18	24.82	3.83	1.80	0.70	38.9
Average of full bloom . .	7.38	8.91	55.17	25.19	3.33	1.43	0.36	25.2

From the results of his numerous analyses of grasses, Professor Collier concludes that usually, as a grass grows older, the amounts of water, ash, fat, and albuminoids that are contained in it decrease, while the amounts of carbohydrates and of cellulose increase. Non-albuminoid nitrogen decreases until the time of blossoming, or just after blossoming, and subsequently increases during the formation of the seed. Many exceptions to and variations from these rules were noticed, however.

Analogy of Grass to Oats.

In general, it may be said that the character of a grass, like timothy, is really so much akin to that of oats, that in all probability one might reason correctly enough about the grass crop from what is known of oats. It will be remembered that Arendt found that the largest rate of increase of dry matter in his oat plants was at the time when their stalks were shooting up, and that there was another considerable gain after the time of flowering, while during the final period of ripening the gain of dry matter was very small. In like manner, there is a feeling among practical men in this country, that timothy grass gains very considerably in weight after it has flowered and before the seeds have ripened. Some observers say that a crop of timothy hay may gain as much as one third in weight, if it be left to ripen, over what it would have yielded if it had been cut at the moment of flowering, or just before.

Other investigators have found that the oat plant increases very much between the time when the ear first appears and the end of blossoming, the general conclusion being, that, if the crop is to be mown for hay, we can assuredly realize all there is to be gained in respect to weight if the crop be mown when the seeds are in the milk or in the dough, and that, unless the mowing is delayed until this time, or until very near this time, there will be obtained a lighter yield.

It will be remembered that, in the case of oats, there was a particularly large gain of dry organic matter at or before the time of shooting, in case the crop had been manured with easily soluble nitrogenous fertilizers, while in the presence of less active nitrogenous manures the gain tended to appear at a later period, — either at the time of blossoming, or sometimes even later than that. It is true, however, that a large proportion of the increase of dry matter during the period of shooting was cellulose, pure and simple. Arendt found twice as much of this substance in a given weight of his dry oat plants after the shooting as before. More of the other carbohydrates also were produced at the time of shooting than at any other period in the life of the plant. Nitrogenized matters were found in large proportion in the young oat plants, and it is notorious that young grass is specially rich in nitrogen; but, as has just been said, it happened, as the plants grew older, that cellulose and carbohydrates increased more rapidly than the nitrogenous substances, i. e. during the times of shooting and flowering.

Hence the advice that is so often given, to mow grass at the beginning of flowering, or even before flowering, should be taken with many grains of allowance. It is true that, if grass be mown early enough, the quality of the hay may be excellent, and that a larger proportion of it will be digested than is the case with late cut hay. But these advantages would be most clearly marked if the grass were mown before its stalks had shot up, i. e. if it were mown at a time when the yield of hay would be conspicuously small; and precisely the same kind of reasoning will apply, though perhaps somewhat less strongly, to grass that is cut at any stage short of practical maturity.

Objections to cutting Grass early.

Herein lies the objection to early cutting, viz. that, though excellent for certain purposes, the crop of hay is not large enough to justify any such sacrifice of quantity to quality. It has been urged, at one time or another, that, if grass is cut when in flower, the leaves will have by that time attained very nearly their full size, that they will hold fast to the stalks, and that a good part of the nutritive matters, particularly the nitrogenous matters, which have been elaborated in the plant to form the seeds, will still remain distributed pretty evenly throughout the entire plant, i. e. in the stalks and leaves. It has been urged that, even at the time when the first blossoms begin to appear upon timothy, no one part of the plant can as yet have been much impoverished by the movement of its constituents towards the seeds that are to be. But as bearing upon this point, it is to be remembered that Arendt noticed a very remarkable gain of nitrogen compounds just after the oat plant had flowered; that is to say, between the actual flowering and the first stages of ripening of the seed. The amount of nitrogen assimilated at that time by Arendt's plants was in fact larger than that taken in at any other period. During the time of blossoming, the percentage of nitrogen in the entire plant was lower than at any other period, because, of course, of the great amount of cellulose that had been produced just before that period. But the subsequent gain of nitrogen was so large, that the grain-bearing plants were one third richer in nitrogen than the plants in flower.

About two fifths of the entire nitrogen in Arendt's crop were taken in between the time of blossoming and that of partial ripeness, when the seeds, though still soft, could be shelled; and nearly two fifths of all the organic matter of the plants were also produced at that period.

The Notion that Ripe Grass is Sweet.

Stress has often been laid upon another point, suggested by what happens in the case of Indian corn and sorghum plants as they approach maturity; viz. that the ripe stalks of grass will naturally be sweeter, and will contain more sugar, than is present in the plants at any earlier period. It is only when sorghum plants have come to full maturity that their stalks are really rich in sugar. It was a fair enough inference that some such increase of sweetness as this may occur in the other grasses; and it is not improbable that a more or less conscious appreciation of this conception may have had considerable influence in leading practical men to prefer "ripe" grass for hay. But on trying to test the accuracy of the idea, Collier was unable to satisfy himself that it is well founded. From a careful study of meadow foxtail (Alopecurus pratensis) at various stages of development, it appeared that sugar did not increase as the age of the grass increased. On the contrary, the amount of sugar appeared to decrease with age.

Practical Men mow late.

It will be well to consider in how far the chemical knowledge hitherto acquired in respect to grasses consists with the habits and opinions of practical men as to the best times for cutting grass. The Romans, as Loudon has set forth, mowed their meadows when the flowers of the grass had begun to fade; and until a very recent period the practice was universal to make hay very late in the season. Marshall, in his day, made the capital point that the system of late mowing was a direct inheritance from the times of common fields. When there was a common right of pasturage on all mowing lands up to the beginning or the middle of May, the hay crop would inevitably fall late; and when, in addition to the spring feeding, the common right of pasturage came in again the moment the hay crop was taken off the land, it was no more than natural that the owners of the hay should let that crop stand as late as possible, in order to get the largest possible bulk, for only one crop could be cut each year.

Forty years ago there were farmers in the vicinity of Boston, even those whose operations were the most extensive, who made a point of beginning their haying the day after the fourth of July, or the Monday after the fourth. This remark applies to men who were accustomed to secure very large quantities of hay by means of scythes and the other hand implements of those days, and it well illustrates the old idea that time should be allowed for grass to ripen. Nowadays most haymakers in this locality have been at work for a full month when July sets in, and almost every one strives to mow the grass before it has wholly turned into straw.

In view of the fact that June-grass blossoms some weeks before timothy, old fields which have "run out" and become filled with it naturally need to be mown much earlier than those which have recently been laid down, and are still in good condition. It is not improbable, indeed, that the change in the time of hay-making near Boston may be due in part to a considerable depreciation in the condition of the fields, and the greater prevalence of the inferior kind of grass.

To-day many farmers speak of mowing timothy when it is "in the second blossom," i. e. at a time when the very tips of the spikes of grass are in flower. Manifestly, the term seeks to express the idea that it is best to cut the grass in late blossom, or rather after the time of flowering. In general, it would appear that the mowers wait until the bloom is practically off the grass, and until a good many seeds are in the dough.

There can be little doubt, when the chief object is to get the largest yield of merchantable hay from a given cutting of grass, that the moment to be aimed at should be that when the larger part of the grass plants in the field are out of blossom, and their seeds have begun to mature. The ideal moment would be when the seeds are considerably developed, yet not enough so that, by the process of after ripening, they may become liable to shake out of the ears, or to pass undigested through the stomachs of animals. If the grass is left standing too long, most of the seeds will subsequently become mature enough to shake out or to escape digestion, while the bottoms of the stalks will turn in some part to hard, unpalatable straw. Even when timothy grass has been cut at the best possible moment, taking the whole field into consideration, many seeds will usually be destroyed by mice and insects after the hay has been stored.

The strong arguments in favor of rather late cutting are, that much more hay can then be obtained from each particular field; that the hay is more easily made, i. e. more quickly, with less labor, and at less risk; that it keeps better; and that it is excellent fodder for any kind of stock, and particularly for working horses.

Doubtless some few farmers mow their timothy rather earlier than the majority do, i. e. they may cut it when it is actually in blossom. Indeed, several farmers, who pride themselves on making super-excellent butter to be sold at exceptionally high prices, have urged that early cut hay is best for their purposes, since butter of excellent color and flavor is readily made from the milk of cows that are fed upon such hay. But the argument loses much of its force in view of the well-known fact, that not so many pounds of butter can be got from the small crop of early cut hay as are obtained from the larger crop of hay that has been allowed to grow towards maturity.

Maintenance of Grass-Fields influenced by the Time of Mowing.

There are, of course, other considerations besides mere quantity, or even quality, of a single crop, that have their influence upon the time of cutting grass. It is an object for the farmer to keep his grass lands in good condition, so that they may be mown again and again during many years, and their condition may be largely dependent upon the time of cutting.

If grass is mown early, before the plants have spent their force in forming flowers and seeds, the chance of a good crop of rowen will be greatly increased, and the rowen will shield the roots from the sun and keep the ground from baking. On the other hand, if grass is cut when its seeds are somewhat advanced, the roots will be subjected to a very severe strain in the dry summer weather, and, even if by chance there should be rains after the hay had been carried off, it might easily happen that the stand of grass would be less vigorous than if the grass had been cut still later. For if the crop were ripe enough to shed some seeds, the ground would be resown, and young grass would spring up to replace any old roots that may have perished.

This notion of reseeding the land seemed important in the eyes of our forefathers, and many of them complained bitterly, on this very account, of the absurdity of the new-fangled notion of cutting grass early. So too, when mowing-machines were first used, the complaint was made that they injured the fields. The fact being that the machine, by cutting much more grass than could be cut with scythes, enabled the farmer to finish haying sooner than he used to do. In the times when the farmer was compelled to leave much grass until it was over ripe, his fields were continually reseeded without any effort on his part.

This fact is one that is well worthy of being borne in mind and of being acted upon. It teaches that the reseeding of grass lands is not to be neglected, and it illustrates the great influence that the adoption of any new method of farming may exert in directions that are wholly unexpected, and perhaps antagonistic to the real purpose of the method.

From this point of view, also, it would appear that, as regards the mowing of timothy, the true point to be aimed at must be a moment soon after flowering, when there is no great risk that the roots of the grass will be injured by exposure to sun and drought. And it is not impossible that, unless the grass can be mown at that stage, it might be better to leave it standing until some seeds are ready to fall, according to the old practice. It would seem, however, even here, that it would be better to cut the grass when in the milk, and to subsequently sow seeds expressly, at an appropriate season. No doubt much good might be done at small cost by harrowing grass fields that show signs of having suffered from the weather, and rolling in a light dressing of seeds; and it stands to reason that, if thus much is to be done, it will be still better to spread some kind of fertilizing material upon the land before harrowing it.

Impracticability of Mowing all Fields at their Best.

But let the farmer do his best, he can never cut all his grass at that one particular stage of development which he may especially esteem. What with the weather to hinder him, and the inevitable tendency of many fields of grass to come to maturity at the same moment, he must always, if he would prosper, cut some grass very early, that is to say, earlier than he would like, and other fields later. It will not do to wait until the first field is at its best, lest other fields should be too far advanced before the first fields have been harvested. So that practically, upon almost every farm, grass does get cut at very different stages of maturity. The modern tendency is to begin haying so early that no grass shall be cut too ate; and this plan is unquestionably better than the old one, of waiting until the first field of grass upon the farm was "ripe."

It is a question whether it might not be wise, in many localities, for the farmer to pasture stock for a short time in the early spring upon such of his old mowing-fields as are best suited to bear the weight of cattle, for the express purpose of making the hay crop of those particular fields come in late. Here at Boston, for example, it may well be possible that the old practice of beginning to make hay in July was based primarily on the probability that there will be better hay weather in that month than in June. June is not infrequently cool and rainy in this locality, and it is seldom that any continuous hot weather occurs before the fourth of July. There is, on this account, a real advantage to be gained, on the average of years, by haying in July; and it would be well, when possible, to adjust the ripening of the crop accordingly. The spring pasturing of mowing-fields is often practised in Europe, and has been commended there as tending to check early weeds and some of the ranker kinds of grasses.

European Hay better than American.

Were it not for the summer droughts, which hamper the American farmer, it would probably be well in some localities to establish grass fields of such character that they could be mown early and often. For where the purpose of the hay crop is to feed cattle upon the farm, and there is no intention of selling any of it directly, it might be advantageous to cut some grass as grass, i. e. just before the flower-stalk has begun to shoot upward. When cut at that stage, or earlier, grass is specially nutritious, and if there were moisture enough in the soil new leaves would immediately spring up for the second cutting.

The moister climate of Central and Northern Europe, and the absence of fodder corn and corn-stalks there, are prominent reasons why the grass husbandry of those countries differs so decidedly from ours. European meadows often carry a considerable variety of grasses, some of which (like meadow foxtail) are fit to be mown early, and others late; while in America the farmers chiefly confine themselves to one of the most grain-like of grasses (timothy), and count upon its stalks shooting up to a good height, in spite of some dry weather as the crop approaches maturity.

Many years ago, after a severe drought in England, some cargoes of first quality baled hay that were sent by steamer from New York to Liverpool could not be sold there except at a sacrifice, because of the unfamiliar appearance of the hay; and from numerous analyses of American grasses, it appears that the hay of this country does actually differ appreciably from the hay of Europe. From the following table of comparisons drawn up by Professor Collier, it will be seen that American hay usually contains a smaller amount of nitrogenous matters than the European, and a larger amount of carbohydrates. There is less cellulose also in the American hay. For the sake of closer comparison all the analyses given in the table are of hay that has been dried completely at 212° F.

AVERAGES OF ANALYSES OF AMERICAN HAY.

	77 Analyses of Wild Grasses.	21 of Grasses from Pennsylvania.	19 of Grasses grown at Washington.	6 of Orchard Grass from various Localities.
Ash	7.90	7.95	7.44	7.38
Nitrogenous matters (= N × 6.25) .	8.20	10.04	10.25	8.91
Carbohydrates	53.90	55.75	55.82	55.17
Crude cellulose	27.10	23.14	22.47	25.19
Fat, etc.	2.90	3.12	3.52	3.33
Per cent of the nitrogen in the form of non-albuminoid matter . . .	34.70	30.10	18.30	25.20

AVERAGES OF EUROPEAN ANALYSES, AS GIVEN BY WOLFF.

	Hay of Medium Quality.	Good Hay.	Very good Hay.
Ash	6.30	7.23	8.24
Nitrogenous matters (= N × 6.25)	10.74	11.32	13.77
Carbohydrates	46.53	47.84	48.93
Crude cellulose	34.09	30.69	25.77
Fat, etc.	2.34	2.92	3.29

One reason why clover is often sown with timothy in this country is that the clover in fair seasons will give a good aftermath, such as might not have been got if timothy had been grown by itself.

By cutting some hay-fields very early, as was just now suggested, when the plants are still in the condition of pasture grass, it would be possible to postpone the harvest proper on those fields to a late date, and thus to get so well started that a large proportion of the hay-fields upon the farm could be mown at the best possible season.

One objection, it should be said, to cutting timothy late, is the somewhat greater liability of the crop's "rusting" when the harvest is deferred. Near Boston, the fungus which causes the grass to rust appears rather late in the season.

Ripe Grass dries quickly.

As has already been intimated, one palpable advantage in cutting over-ripe grass is that it takes comparatively little time to cure it. It has often been urged, that late cut timothy can be made into hay very readily, because a large part of its juices have dried out of it naturally. Even in the old days of scythes and hand-rakes, farmers often "made" their late cut hay in a single day, for there was so little moisture left in the standing grass that very little time was needed to dry this remnant off.

All this consists perfectly with the notion of backward farmers, that it is unwise to mow grass before it is "ripe," since immature grass "shrinks" enormously when made into hay. It explains, moreover, a good part of the disagreement which exists among men as to the risk of storing partially cured hay in barns. Old straw-like hay might be stored with perfect safety after a day's making by the old methods, while the hay from young grass might all spoil in the mow if it were housed after precisely similar treatment.

So too, some part of the discussion as to the comparative merits of curing hay rapidly by tedding, or slowly in swaths, windrows, and cocks, doubtless depends upon the condition of the grass when cut. It was not a bad taunt that was thrown out at one of these debates, that "it costs so much labor to dry young grass by the cocking process, that the farmers who practise this system take care not to cut their grass before the second blossom." Another point to be considered at the hay harvest is, that, in case any fields must be neglected until the grass will have had opportunity to become dead ripe, it may be good policy to choose those that stand in need of being reseeded.

Some years ago it was urged by several writers that it would be well to steam hay before feeding it out to cattle. The scheme was found to be too costly in practice, generally speaking, because of the labor involved in it. But it is noticeable that, if steaming were a practicable process, it would probably be best to cut the grass as late as could be done without losing too many of its seeds.

New-made Hay is Laxative.

One strong objection that works against the early cutting of hay is the tendency of hay made from immature grasses to loosen the bowels of animals that feed upon it. This fact alone precludes the use of such hay for working horses. All newly made hay has a certain laxative and weakening effect upon animals, which is deprecated by practical men. Such hay cannot be sold to the keeper of a livery stable, because, as he would say, he has no wish to soften down his horses. Horse keepers are of opinion that this laxative quality of new hay endures until the hay has passed through a process of "sweating," which occurs in the mow.

No matter how dry the hay may be at the time when it is put in the barn, it is held that it will always "sweat" somewhat in the mow. By October the process is completed, so that the hay is fit for use, provided it was ripe enough when mown. But in the case of hay made from young grass, such as rowen, for example, the medicinal quality persists; and such hay is thought to be always unfit for horses that are kept at work, since it is apt to weaken them, to make them sweat easily, and to render them liable to stumble.

Among many conflicting statements that have been published, it is difficult to judge how old grass must be in order that the hay made from it shall be absolutely non-medicinal. Farmers disagree very much in their opinions as to the laxative action of hay made from grass that has not flowered. Some hold that all such hay loosens the bowels as rowen does, while others maintain that timothy cut early in June, before it has shown a blossom, does not disturb the digestion of cattle as rowen does, although the animals are exceedingly fond of it, and prefer it to later cut hay. There can be little doubt, however, that hay from grass cut in blossom, or before, is more laxative than that cut later.

As regards cows, it is not easy to see why the laxative quality of hay from immature grass might not easily be obviated. It is hardly credible, for example, that rowen hay, fed out judiciously to animals just taken in from pasture, should loosen their bowels to an injurious extent. It seems reasonable to suppose that the laxative quality of rowen is similar to that of young, i. e. green grass; and, as everybody knows, cattle suffer from diarrhœa when first turned out to pasture in the spring. The fact is, farmers are apt to keep their rowen hay until towards spring, in order to give it to cows that have recently calved, and in general to refresh their cattle after the winter's campaign on old hay, and it is at that time that they notice the medicinal effect.

The true way would seem to be to feed out the rowen in small proportion at intervals throughout the entire season, or, if there were enough of it, to accustom the cattle to it just as they are allowed to accustom themselves to green grass. It would seem, too, as if an admixture of rowen and straw, or of rowen and bog-meadow hay, might be prepared, at the moment of storing the rowen, which would serve perfectly well to replace ordinary hay in many rations. It is noticeable, when the hay from fields that have been sown with grain and grass seeds is cut so long after the grain has been reaped, that no more than a third or so of the hay crop as put into the barn is old dead grain stubble, that cattle will leave from a third to a half of the stubble uneaten. But when such hay is mown early, the old stubble admixed with it, though present in comparatively large proportion, is eaten up so clean that it is difficult to find any stalks of it left in the cribs. The easy digestibility of the young hay is, of course, one strong point in its favor. It is curious that there should be any hesitancy about admitting the great value of early cut hay, when there is absolutely no difference of opinion as to the supreme merit of young grass. Most farmers believe in all sincerity that there is no food, or mixture of foods, upon which cattle will thrive so rapidly as upon good pasture grass.

Sweating of Hay in the Mow.

The so-called sweating which newly made hay undergoes in the mow or stack, and which is thought by practical men greatly to improve the quality of the hay, at least for feeding working horses, is a mild form of fermentation, which has been studied in England by Percy Frankland and Jordan. They find that the change which the hay undergoes is not a mere matter of oxidation by air, but a true fermentation, dependent on the action of living microdemes. It was found by these chemists that very considerable quantities of carbon and of nitrogen go off from the hay in the form of carbonic acid and of free nitrogen gas during this slow fermentation. Their newly dried hay absorbed much oxygen, even at the ordinary temperature of the air, and gave off a great deal of carbonic acid and nitrogen, though the evolution was more rapid as the temperature increased.

Moreover, after the oxygen which was at first in contact with the hay had been used up, much carbonic acid, though comparatively little nitrogen, was still given off, as a result of the decomposition of oxygen compounds in the hay. That is to say, even in the absence of air, the fermentation went forward through the destruction of certain constituents of the hay that contain oxygen in combination.

It would seem to follow from this, that the common practical rule that the construction of a hay barn should be as open as possible, for the purpose of drying as well as of preserving the hay, must depend primarily upon the power of keeping the hay cool which the open construction gives. The object of the openness is to hinder the accumulation of the heat generated during the act of fermentation, and so to prevent the occurrence of injurious fermentations of other kinds than the simple normal "sweating" of the hay.

When barns were first introduced into England, the objection was made, that hay is more apt to "heat" in barns than in stacks. So, too, in building stacks of hay or grain, pipes or chimneys are often left at the middle, in order that the heat generated by fermentations may be readily discharged.

Frankland and Jordan found, on allowing oxygen to regain access to hay which had been deprived of it, that the evolution of nitrogen would begin anew, though somewhat less vigorously than at first, and that it would continue for several months, as well as the evolution of carbonic acid.

It is commonly held, that this autumnal fermentation in the mow or stack must be allowed to run its course before hay can be safely pressed into bales for transportation.

"Shrinkage" of Grass and Hay.

According to Loudon, the waste of grass on being dried into hay is supposed to be three parts in four, by the time it is laid on the stack; it is then further reduced by heat and evaporation to the extent of perhaps one twentieth more in the course of a month, so that 600 lb. of grass finally yield 95 lb. of hay, and between this weight and 90 it continues through the winter. In case the hay is sold during the next spring or summer, perhaps enough more of its weight will be lost by exposure to sun and wind, on moving it from the stack and marketing it, to reduce the weight to 80 lb. Speaking of the damp English climate, Loudon holds that the same hay which would weigh 90 lb. if delivered in the winter after it was harvested, will weigh 80 lb. next summer. In England a "truss" of new hay is rated as weighing 60 lb., and a truss of old hay as weighing 56 lb.

In New England, the question as to the amount of shrinkage which hay suffers when stored in barns has commonly been debated in terms of price rather than of weight. Thus, it has happened that the main point in the discussion has been obscured by considerations relating to the cost of labor expended in pitching and hauling the hay on moving it into or from the barn, and to the interest on the money which would naturally come into the farmer's hands several months earlier in the one case than in the other.

The rule has sometimes been laid down, in this sense, that about one third of the price of the hay, as it lies in the field all ready to be housed, should be added after the hay has been in the barn for two or three months. Or, stated in other terms, it is held to be as well, or perhaps rather better, for the farmer to sell hay at $15 the ton from the field, than at $20 the ton next winter from the barn. It has been suggested, however, that hay which is freely salted when stored will weigh out heavier in the winter than would be the case if no salt were used. This result may be due in part to the tendency of the salt to attract moisture, and so hinder the hay from drying off unduly; or it may depend somewhat on the salts having checked the process of sweating or fermentation, which even the driest of hay undergoes when first placed in the mow.

According to a writer in the Rural New Yorker, experiments have been made in this country, extending through three years, to determine accurately the shrinkage of hay. Seventeen different lots of mixed clover and timothy hay, obtained from grass cut at different stages of growth, from the time it began to head until it was nearly dead ripe, were weighed when put in the barn, and again in December, or later in the winter. In some instances the parcels of hay weighed two tons, and in others 800 lb. each. The largest observed shrinkage in weight was 36%, and in four separate parcels it was over 30%, while the least amount of shrinkage was 12%, in the case of very ripe clover. The average shrinkage was a trifle more than 24%. Whence it appears that hay grown for sale needs to advance not a little in price in order that it shall be worth the farmer's while to winter it.

In no event is it well to keep hay in the barn until the second winter, for chemists long since detected an appreciable diminution of the nitrogen in hay that has been kept more than a year, and there can be little doubt that, after the process of "ripening" has passed by, which occurs soon after the hay has been put in the mow, it does slowly depreciate in nutritive value, either by a process of gradual oxidation, or perhaps by ferment action. Many years ago, Boussingault showed that an animal fed on a given weight of recently made hay did as well as when fed on a corresponding weight of the grass from which the hay had been made. But it is certain that no such favorable result as this could be got on using hay that had been kept two years in a barn.

Other Grasses than Timothy.

If space permitted, much might be said about the various kinds of grasses that are cultivated abroad, or which might be cultivated here, instead of timothy, on soils that are ill suited for that particular kind of grass. The great merit of timothy is, that, under favorable conditions, it yields a very large crop, — a very much larger crop than any of the other grasses of equally good quality, with the single exception of orchard grass. Werner in his "Futterbau" gives the yield in kilograms per hectare of good land of what may be called really good crops of a large number of grasses and clovers. The following items have been selected from Werner's table. From a hectare (= 2.5 acres) of land, there are produced of the specified grasses, on the average, the following number of kilos (one kilo = 2.2 lb.) of air-dried hay: —

The best kinds of Poa, such as June-grass and rough-stalked meadow-grass (Poa pratensis and trivialis)	5,000
Perennial-ray grass (Lolium)	6,000
Meadow foxtail (Alopecurus pratensis)	7,700
French ray-grass (Festuca elatior)	8,400
Italian ray-grass, on irrigated meadows	10,300
Timothy (Phleum pratense)	10,600
Orchard grass (Dactylis glomerata)	15,300
The great Festuca (F. gigantea)	13,800
Ribbon or reed-canary grass (Phalaris)	15,600
Red clover	6,000
Swedish clover	4,500
White clover	2,500
Lupines	5,000
Vetches	4,000
Lucern	8,000

Reducing some of these figures to terms of pounds to the acre, we have as a good European yield of

Timothy	9,300 lb.
Foxtail	6,800 "
French ray-grass	7,400 "
June grass	4,400 "
Vernal grass	2,100 "
Orchard grass	13,464 "

Aftermath is included of course in these estimates, and the large amount of orchard grass as here given must depend in good measure upon the second, or even upon a third crop. Perhaps the timothy crop included clover.

Timothy loves a deep, rich, light loam, plenty of sunlight, and a fair share of moisture, while orchard grass will bear shade very well, and will continue for years to give excellent crops even beneath large apple trees. Orchard grass has other advantages over timothy in that it bears pasturing very well, i. e. it can withstand the biting of cattle; and when young it is esteemed by them highly. Since it blossoms earlier than timothy, and at about the same time as red clover, it is said to be better suited than timothy to be sown with clover for hay. Orchard grass grows most freely upon good deep soils, but it is none the less true that, economically speaking, the proper places to sow it are in the shade of trees, and on light soils that are not suited to timothy. It should be mown rather early, since the hay made after the grass has flowered is, comparatively speaking, harsh or rough, and consequently of inferior quality.

French ray-grass, sometimes called tall oat-grass, which has been occasionally grown together with orchard grass in this country, is said to do well in Europe upon sandy loams that are neither too wet nor too dry. It is not recommended in this country as a grass to be grown by itself.

Probably the different times of blossoming of clover and timothy is a prominent reason why clover hay is less highly esteemed than it should be in some parts of New England. In order to get the utmost advantage from clover, it should be mown before it has gone to seed. But where clover and timothy are grown together, as is the usual practice in this country, if the farmer were to cut the clover when at its best, the timothy would still be so young and green that the total crop would be comparatively light. Hence, he ordinarily lets the timothy come to maturity, and the clover suffer hurt from getting to be over-ripe. There would be less cause for complaint against clover hay if only the clover plant were treated fairly. Even in the best clover regions of Europe timothy is esteemed to be a good grass to grow with clover, and it is thought that the mixture is more nourishing and more palatable than clover alone. But the mixture is there thought of and mown as clover, i. e. as clover with something admixed. It is not thought of at all as timothy with a mixture of clover.

The rapid growth of orchard grass, i. e. its rapid recovery after it has been mown, and its power of resisting drought, are other advantages in its favor. It does better on clayey land than timothy, and it has been said of it that it loves a clayey loam while timothy prefers a sandy loam.

One great objection to timothy is, that it does not yield a good second crop, and it is on this account, as has been said, that many farmers justify their practice of sowing clover with timothy. So too, one reason why red-top is sown with timothy is, that it forms a close sod, which persists each year after mowing, as well as permanently after the timothy has died out. It is admitted in Europe that, for permanent meadows, timothy is inferior to foxtail (Alopecurus pratensis), which is a grass not much unlike timothy in appearance, because the foxtail gives a much more abundant aftermath. The foxtail has the further advantage, that it blossoms a month earlier than timothy, and has a much more tender stalk. But it needs a moist situation and cannot bear drought so well as timothy can. It is unfit for mixing with clover, since it does not come into full bearing until the fourth year, while timothy culminates in its second year. The foxtail bears moisture better than clover, and is well suited to clay lands and those rich in humus, and to irrigated meadows.

There is a coarse grass allied to red-top, called Fiorin, or creeping bent-grass (Agrostis stolonifera), which seems to be a mere variety of Agrostis alba (white bent or English bent), that has often been commended by English writers for wet lands. It is held to be specially well adapted for moist peaty soils, and for bog meadows that are occasionally overflowed. Three tons to the acre are said to have been repeatedly obtained in England. Sinclair has said of this grass, "On mere bogs fiorin yields a great weight of herbage, and is perhaps the most useful plant that bogs can produce." The hay from it is readily eaten by horses as well as by neat cattle, but is said to be difficult to dry in the damp English climate. It is kept there in particularly small-sized stacks, on this account. Ribbon grass is another coarse, free-growing grass, well suited for meadows that are wet with flowing water. An account of this grass with analyses of it, and of blue joint grass (Calamagrostis Canadensis), will be found in the Bussey Bulletin, II. 130.

Annual Weed-like Grasses.

Among grasses which specially interest the yeoman farmer, certain annuals should be mentioned which ripen in late summer and are commonly classed as weeds. They are the false millets, called bottle grass or panic grass (Setaria), barn-yard grass (Panicum Crus-galli), and finger grass (Digitaria). These grasses play a not wholly unimportant part in the agriculture of New England, in that large quantities of them are eaten by sheep and store cattle that are permitted to pasture upon the plough-land after the summer's crops have been removed.

The chief trouble with all these grasses is that they are really grain-bearing plants, that pass into the condition of straw and chaff before the farmer has had time to make up his mind about harvesting them. They grow with the weeds proper in potato-fields and corn-fields, upon stubble-fields, in hay-fields where the sod is not densely matted, and in waste places generally. The abundant seeds of the panic grasses are much relished by birds, and domestic fowls put a good many of them to profit. Young turkeys, in particular, are said to thrive upon them. Great flights of blackbirds subsist upon them in late summer.

While standing in the fields, and especially when mature, these grasses tend to repel animals because of their rough, bristly, hairy spikes. But when converted into hay they are eaten readily enough by neat cattle and sheep. Dr. Warder of Ohio reports a case where the growth of bottle grass in one of his corn-fields was so luxuriant that he mowed it and made it into hay. To his surprise, he found in midwinter that his cattle relished this hay exceedingly. They ate it voraciously, and preferred it to timothy or blue-grass hay. Barnyard grass, being the largest of these volunteer crops, has naturally attracted more attention than either of the others, and not a few fields of it have been mown and made into hay which turned out to be excellent. In some poor, sandy, though moist districts in Germany, finger grass is cultivated for hay, and regarded as a blessing.

It will often be well for the farmer to save these autumnal, weed-like grasses, either as hay or as ensilage, when they force themselves upon him. Some persons have urged that it would be well to cultivate barn-yard grass as a forage crop. The objection to this idea is, that a much larger amount of equally good or better fodder could be cut from a given area in the form of several of the millets; and that the yield of nutritive matter obtainable from it on good land would undoubtedly be less than could be got, for an equal expenditure of space and power, from other forage crops.

There would appear to be one attribute of the barnyard grass, however, which might give it an advantage over the millets and other competitors in some special cases. If, as seems probable, it could be sown very early in the season, — possibly even the year before the harvest, or at any odd moment when the work upon a farm was slack, — and then be left to itself until tolerably late in the season, so that it could be harvested at a time of comparative leisure, it might be regarded as one resource for lightening labor upon a short-handed farm. We are so accustomed to see it growing as a weed, in spite of manifold hindrances and difficulties, that it would not be safe to predict just how it would behave under favorable conditions, or when it would ripen if cultivated. When growing upon mere gravel, each particular stalk of barnyard grass throws out a large number of strong shoots, and there is no doubt that much fodder could be got from it if it were possible to shave the plants off close to the earth, as pasturing sheep might do.

Highly interesting experiments might be made by trying to put these grasses to methodical use; and the same might be said, indeed, of many other kinds of weeds also. Chemically considered, most weeds are highly charged with nutritive matters, and ways and means could doubtless readily be found out, after a little study, of utilizing them. Processes of ensilaging would naturally suggest themselves as one resource, the more especially because applicable even late in the autumn, and because the seeds of ensilaged plants would neither be scattered about the barn floor, nor yet be apt to escape digestion in the intestines of animals.

CHAPTER XXII.

PASTURES.

One fundamental conception in the minds of many New England farmers is, that the land devoted to pasturage upon any given farm should either be poor land or rocky land, or land so inaccessible that it could hardly be used for any other purpose, unless, indeed, it were left to cover itself with wood. The conception is a good one, and there are reasons why it should have special force in this region. It is true, of course, of many other countries, that there are certain situations where the land must be used for pastures if it is to be used at all. The sides of high mountains, as in Switzerland, and of many steep hills all over the world, must be so used, because, if the sod were once broken, the soil would speedily be washed away by rains.

In Europe, however, these wild pastures occur only in special localities, where they are put to use either for producing butter, cheese, or wool; and it is customary in that country to recognize another kind of rich or feeding pasture, which is used for fattening horned cattle, or for keeping working oxen or milch cows, or the choicest mutton sheep. These richer pastures are usually maintained in such condition, that, if cattle were kept out of them and the grass were left to grow, they might justly be regarded as good mowing-fields. It sometimes happens, in fact, that these fields are mown and depastured alternately. In the vicinity of Boston there are several reasons which work against the adoption of this system. Most of the beef consumed in the locality is brought nowadays from distant regions that are comparatively speaking wild, either at the West or the North, for there is no longer any adequate profit to be gained in lower New England by rearing and fattening animals. But there is nevertheless much rough and poor land that is fit for nothing but pasturage which needs to be put to use, and the usual plan is to keep cows upon it for the production of milk or butter.

So much hay is needed withal for use during the long winters, and there is so quick a demand for merchantable hay, that the farmers are incited to grow hay on all land where it can be grown and harvested with advantage, rather than to establish rich feeding pastures such as are seen abroad. Exceptions to this general rule occur of course almost everywhere, and there are localities in this country where many rich pastures are kept up; but the practice is none the less an exceptional one. In New England the problem is clearly how to make the most of the rough rocky or sandy pastures, — to learn how to keep them from "running out," and how to treat them in order to obtain the largest possible profit.

Rough Pastures an Incident of Low Farming.

It may be said of these rough pastures, as contrasted with the smooth feeding-grounds of Europe, that it would be hard to find a better illustration of extensive as against intensive farming than they afford. As has been already explained, it is possible in some situations to obtain the largest profit by expending much labor and money upon the land for the sake of getting large crops, even at considerable cost, while in other places it will be proper to expend the least practicable amount of labor and money in order that the cost of producing whatever is produced may be kept at a very low point. In respect to their pastures, at least most New England farmers are so circumstanced that they are compelled to manage them on a basis of low farming.

It has happened in Europe that the amount of pasture land has largely decreased as the country became more densely populated. As nearly as can be made out, the proportion of pasture land to arable land in England in the fourteenth century was as 20 to 1, though it was known even then that the amount of pasture had been gradually decreasing. Nowadays, the proportion of pasture to arable in Great Britain is barely 1 : 1, and until very recently the tendency has constantly been towards the diminution of the area of pasturage. Under the conditions that had obtained in England for a century or more until the present time, it was found to be more profitable to grow, in addition to grain, great crops of roots and clover, or the like, and to feed cattle upon these products, together with oil-cake and straw, than it would have been to pasture the animals. Quite recently, however, grain has been imported so cheaply into England, and the cost of agricultural labor in that country has so decidedly increased, that the area of pasture land now tends to increase, and during the last few years the increase is said to have been rapid.

Only a few years since, it was argued in England that the mere straw of a good wheat or bean crop is worth nearly or quite as much for feeding animals as the whole produce of many an ordinary pasture. The matter of course turned largely on the fact, that, by keeping stock up and feeding them heavily, as was customary then in England, enormous quantities of manure were obtained, and proportionally large crops of grain were grown by means of the manure. The damp climate of England lends itself to this system of husbandry by enabling the crops to put the manure to use.

Where the supply of land is limited, and the demand for agricultural products is unlimited, it is profitable to cultivate land deeply and frequently, to manure it heavily, and to irrigate it if need be; in short, to work it to the limit of its capacity. But in the face of such conditions as these pasture land cannot long exist, and even mowing lands can hardly be tolerated, unless indeed their purpose is to furnish hay of superior quality for city horses and pleasure horses that are kept for hunting or riding.

It should be said, in passing, that the parks of England have always been an exception to the foregoing generalization. Enormous tracts of park land are there pastured, some with sheep, some with cattle, and some indeed with deer, and this pasturing of parks is an important branch of husbandry. But it is plain that the money thus gained is of the nature of salvage from a wreck, — the beauty and the privacy of the park are the first points to be considered. These are the crops, so to say, which the land is made to bear, and their value, like their cost, is very great. After these considerations have been satisfied, anything which can be gained from the land without interfering with its beauty or its privacy, whether by means of pasturage or in any other way, may be counted as clear gain.

It is an interesting fact withal, that much of the park land of England is said to be of rather inferior quality; well enough suited for pasture land indeed, in the American sense, but not so suitable for tillage as the generality of the land that is actually tilled. Advantage might be gained, no doubt, in many situations in this country, by copying some features of the English methods of managing such land, either by maintaining permanent pastures as good as theirs, or, at the least, by establishing permanent mowing-fields of suitable grasses upon light lands that are unfit for timothy, instead of reseeding them at frequent intervals, as is the custom now. On fairly good, well-moistened land, the American method of growing timothy is unquestionably a good method. But on poorer land, some system which looks to grasses of lighter yield indeed, but fitter quality, would be better. And this last-named system would be closely allied in its essential features to the method now actually practised in Europe.

Land cannot be fully used by pasturing it.

It may be said of land devoted to pasturage, that only a thin layer of the surface soil is put to use, while by the deep cultivation that is required for roots and other hoed crops, the land can be utilized to a much greater depth. So long ago as 1800 the English Board of Agriculture reported to Parliament that an acre of clover, tares, rape, potatoes, turnips, or cabbages will furnish at least thrice as much food as the same acre would have done had it remained in pasture of a medium quality; and consequently, that the same extent of land would maintain at least as much stock as when in grass, besides producing every other year a valuable crop of grain; and this independently of the value of the straw, which, whether consumed as litter or as food for cattle, will add considerably to the stock of manure.

Soiling or Pasturage.

In case a New Englander should wish to establish rich pastures, for the support of milch cows, for example, the question would immediately arise, whether it would not be better, all things considered, to "soil" the cows than to pasture them. That is to say, Would it not be best to grow great crops of rye, oats, maize, barley, and sorghum, to be mown before maturity, or clover, hungarian grass, and cow peas, to be cut green, and fed out to the cattle in the barn, rather than to strive to maintain for them pastures equal to those of some of the moister regions of Europe?

It is evident enough that even in Europe rich pastures often depend in some measure upon tradition, not to say superstition, rather

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than upon fitness. Most of them have been inherited from times when artificial manures were not to be had, and when it was regarded as an essential tenet of good husbandry that land should be made to support itself. The matter is greatly complicated, moreover, with legal restrictions and old forms of leases, and incumbrances upon land, that have no earthly significance nowadays, except that they hamper the farmer and prevent him from using the land as he might like. It is probable that there are many pastures in Europe to-day that would yield a much higher profit if they were worked as hay-fields, and the hay were sent to the great cities for sale. It would be an interesting problem in practical agriculture to determine what method of keeping up the fertility of such fields would be the most economical, all things considered.

In Europe, the comparative merits of soiling cattle, or of pasturing them upon rich pastures, have been not a little debated. It often happens there that the advantages of the two plans seem to be pretty evenly balanced, though it is recognized that the question has so many different bearings that it is hard to arrive at any general conclusion which shall be applicable to all cases.

Soiling is specially esteemed in countries where lucern and sainfoin thrive. Neither of these crops is well suited for pasturing, but where they can be grown successfully it is easy to obtain from them large quantities of fodder, both for soiling cattle in summer and for making hay against the winter's need, and this at comparatively small cost for labor and manure. Under such conditions of soil and climate, soiling is forced upon the farmer. He has really no choice in the matter. But with plants that can be depastured the problem is less simple.

Amount of Nutritive Matter from a Field when Soiled or Pastured.

One difficulty encountered in the very beginning by the scientific inquirer is to determine how much nutritive matter can be got from a given field of grass or clover by the method of pasturing, as compared with that obtainable from the same field by the method of soiling. Complications immediately arise because of the waste due to the treading of the animals, to their unequal feeding, and to their dung killing or injuring the grass where it falls. Attempts have been made to obtain an approximative answer to this question by plucking young clover plants from one part of a field, in imitation of the feeding of cattle, and subsequently mowing the plants from an adjacent part of the field when they were in blossom. The results obtained were as follows: —

Red Clover.	Yield in Kilograms per Hectare. Dry Substance.	Nitrogenized Matters.	Carbohydrates.	Cellulose.	Ash.
1868, plucked	4126.0	1143.1	1943.8	666.5	372.9
1869, plucked	4138.5	1121.4	1953.0	692.8	372.9
1868, mown 3 times	6962.3	1462.0	3136.6	1824.6	538.6
1869, mown twice and then plucked	6614.0	945.2	3503.4	1752.5	413.2

The agreement between the two years is remarkably close, excepting the nitrogenized matters of the mown clover. Total product, nitrogenized matters and carbohydrates are all larger in the case of the mown clover than in that which was plucked in imitation of the pasturing of animals. In order to test the question as to the comparative digestibility of the two kinds of fodder, Weiske fed a couple of year-and-a-half old wethers, first with the mown hay and then with the plucked hay, and obtained the results given in the table. The crops of 1869 contained the following amounts of digestible matters (kilos) per hectare:—

	Plucked.	Mown twice and then plucked.
Organic matter	2341.0	3930.4
Nitrogenized matters	876.9	599.2
Fat	135.1	156.8
Cellulose	465.3	866.0
Carbohydrates	1363.6	2308.4
Ash	116.0	118.2

Whence it appears that there was a larger yield of digestible nitrogenized matters from the young clover, and a smaller yield of digestible carbohydrates and cellulose. Nitrogenized food is, as a rule, more costly than the carbohydrates; hence it would seem, at first sight, as if the superior quality of the pastured grass might more than balance the larger quantity of mown hay. This is evidently simply a matter of figuring: it could be answered by referring to the prices of nitrogenized matters and carbohydrates in any given locality. But in the computation an allowance would have to be made for the costs of mowing and carrying the green fodder, or of making the hay. Local circumstances would have to determine whether it would not be better to buy cotton-seed meal or malt sprouts, or some other highly nitrogenous food, to mix with the mown clover, than to content one's self with the smaller gross yield of material obtained by pasturing.

It should be said that these experiments with red clover do not necessarily apply very closely to pasture grass, which withstands the biting of cattle much better than red clover can, and which would perhaps give a larger yield of gross product when constantly cropped than red clover could.

The general conclusion drawn from these German experiments seemed to be, that, if the soil were good enough, and the conditions were sufficiently favorable to admit of mowing a field three times a year, it would be more profitable to soil cattle upon the produce of such a field than to pasture them there, while, if only two cuttings could be made in a year, the advantages of soiling might be questionable. For such fields as these there is an alternative method, which is employed in cool climates. That is to say, instead of soiling the cows, they may be tethered methodically upon the grass-land, as is often done in Denmark. In localities where cattle are tethered or soiled, fences are wholly superfluous, and are in fact unknown.

The soiling of grass is evidently at its best in places where many cuttings can be got from the fields each year. This is seen at the irrigated meadows below Edinburgh, where as many as four or five cuttings of young and succulent grass are obtained each season. There is a seven-acre meadow at another locality near Edinburgh that has produced from four cuttings sixty long tons of grass to the acre in one year; which means more than twelve tons of hay to the acre. Such grass is so rank that it has to be cut very often, or it would rot at the roots. It is to be remembered withal, that there would be no sense in pasturing such land, even if that were practicable, since it receives already more manure than it can put to use. The droppings of animals upon such land would be worse than lost, — they would be a mere incumbrance. So with meadows that are irrigated, not with sewage like those at Edinburgh, but with brook-water. They would often, practically speaking, be sufficiently manured by the water, and would not need the dung of the animals that were fed from them. In many cases, this dung had much better be put upon other fields. Poggendorff, in his "Landwirthschaft in Belgien," tells of some warped meadows near Ghent, where the grass is cut three times a year, yielding in favorable seasons four and a half tons of hay to the English acre.

In all such cases there would be special reasons why soiling would be better than pasturing. One great advantage in soiling, that is obtained in all cases, is the power it gives the farmer of distributing the dung of his cattle according to his own pleasure.

When cattle are at pasture, their manure is of course scattered here and there, without any semblance of regularity. In some parts of the field, where the cattle rest in the shade or sleep at night, the land is very much over-manured, while other parts of the field get no manure at all. There is a considerable waste of manure withal, what with the decay of the dung in full air, and the consumption of its nitrogenous constituents by insects.

Waste of Dung in Wild Pastures.

There can be no doubt that the dispersion of dung in New England pastures is a great source of waste. All experience teaches that, if ten tons of manure be spread upon an acre of land, it will exert a very beneficial influence upon the growth of the crop, whatever the crop may be; but if these ten tons were scattered, no matter how evenly, upon a hundred acres of land, it is to the last degree probable that no one would be able to perceive that any good came of it. A certain amount of concentration of force is needed in order to produce useful effects, whether the force comes from dung or from any other source. It is true enough that constant dropping may wear away stones, as the proverb tells us; but the mere pushing or pulling of a young child, no matter how long continued, cannot move a heavy load. And with this last illustration may fairly be compared the action of dung that has been too thinly scattered upon a field; for just as the force exerted by the child cannot overcome friction and inertia, so the too small amount of manure cannot overcome the wasting or neutralizing influences with which it is beset. Washing and leaching by rain, the decomposing action of the air and of living things, perhaps even the absorption or fixing of the fertilizing constituents by the soil itself, may all work to annul the economic action of the thinly scattered dung. Hence, a large bare pasture profits very little from the dung and urine that fall upon it.

Pastures differ from Mowing-Fields.

The problem, how best to manage a pasture, differs not a little from that of keeping up a mowing-field, because the treading, dunging, biting, and resting of cattle have a very marked influence to favor the growth of some kinds of plants and to destroy others. Timothy, for example, which is so highly esteemed for hay, is quite unfit to be sown as a pasture grass, because it suffers very much from the close cropping of cattle. Moreover, a very different result is sought for in pastures from what is expected of mowing-fields. When grass is to be mown for hay, it is thought to be important to have only such kinds growing together as will come to maturity at about the same time, in order that the hay produced may be of uniform quality and duly ripe. But in a pasture, the precise opposite of this is desirable. In the pasture, there will be needed a great variety of grasses, — some that come up early in the spring, and others that prosper best in autumn. It is well to have some kinds that mature early, some that flourish in the heat of summer, and some that come on later. In short, the aim is to have in a pasture a succession of succulent and nutritious plants, from early spring to late autumn. In New England the problem nowadays, and it will doubtless be the same for many years to come, is, not so much to keep pastures in first-rate condition, as it is to keep them from actually running wild; and especially to subdue those that have already run wild.

Pastures may run out or run wild.

There are two distinct tendencies to be seen in the pasture lands of this region. They tend, upon the one hand, to run wild, and upon the other, to "run out." Much of the pasture land in New England, perhaps the larger part of it, has never been really subdued. The first settlers cut down the original forest, burnt the logs and brushwood, and, after getting a crop of rye from the ashes, either left the land to itself to be pastured as long as possible, and again to be cut off and burnt when overgrown with brushwood; or, at the best, in later years the practice has been to scatter with the rye on the burnt land such grass seed as has been shed by hay in the barn. Such seed, that is to say, as can be got by sweeping the floors of mows and hay-lofts. In this case also, the land is used as a pasture as long as there is grass enough upon it to tempt the cattle. But, as a matter of course, bushes are apt to spring up on such land, and, in case the forest growth was hard wood, many sprouts from the half-killed stumps come up also, so that after comparatively few years the so-called pasture reverts to woodland, often of a very worthless sort, and has to be cut over and burned anew, like the original forest. One difficulty with which farmers have to deal is to prevent their pastures from thus running wild. But, on the other hand, in case no bushes at all should grow, pastures are still apt to "run out," as the term is. That is to say, the good grasses die out, and their place is taken by other kinds of grasses of much less value. Whether it is that the bad grasses push out the good, and take possession of the ground by mere brute force, as it were, or that the good grasses die out from lack of proper nourishment, has never been accurately determined, though the common belief is that pastures run out in this way because the land is exhausted. Doubtless the two causes above mentioned work to help each other, and a more precise statement of the matter than the one commonly accepted would be to say, that the bad grasses get the upper hand simply because they happen to be specially well fitted to bear the combination of drought and lack of fertility which is to be found in so many old pastures. It should be said, that these run out pastures are found most frequently upon sandy or gravelly plains and hillocks. The original growth of such lands was often pine trees, so that the land got pretty thoroughly cleared at the start, and the tendency for it to grow up to bushes was less than if it had been beset with hard-wood stumps.

The bad grasses, now in question, are classed by farmers under the generic name of "white top." They are characterized by the remarkable facility with which they run to seed; and, as is the case with many other grasses, cattle will not eat them when once they have shot up and formed seed-bearing ears. The wild oat-grass (Danthonia spicata) may be taken as the representative "white-top." It has a stem about a foot high and it flowers in June. When this grass first appears in the spring, its leaves and stems are eaten by cattle, and it doubtless affords very fair pasturage at that time; but it resembles the grains proper in that it quickly shoots up to mere straw and seed, and, as a matter of course, it throws into the seeds most of the nourishment that was originally contained in the leaves and young stem. The seeds are comparatively speaking large, and they are extremely numerous, so that a considerable crop is really grown upon the land.

It is from its conspicuous tufts of seeds that the grass gets its popular name. Many of the seeds are so protected by beard and husks that cattle will not eat them, and in case they were eaten it is probable that their vitality would not be impaired, while other seeds are concealed beneath the leaf-sheaths, so that, in the aggregate, vast numbers of them fall back upon the land to keep up the stock of this peculiarly objectionable grass. Probably it is the enormous production of seeds that enables the white-top to crowd out most other kinds of grasses from poor soils. Where the land is rich enough to permit the growth of free-growing succulent grasses, they would naturally smother the Danthonia.

No doubt, if it were economically possible to collect and steam the dry, repellent stalks and seeds of white-top, cattle would eat and digest them readily enough, and be supported by them. But the burden of the grass is too light to permit any such practice as this to be thought of, and the only alternative is to devise methods of crowding out the white-top by "bringing in" the better grasses.

Methods of renovating Pastures.

Ploughing up the pasture and reseeding it, either with or without cultivation and manure, is one way of proceeding. It is, in fact, the first way that suggests itself to the mind of the average New Englander, and it has undoubtedly been largely practised. It has, however, by no means approved itself to be the best way, even in those comparatively rare instances where the character of the land is such that ploughing is permissible. But upon nine tenths of our pasture land ploughing is hardly to be thought of. Much of the land is so rocky that it cannot be ploughed at all; and in the wild bush pastures, though it is sometimes possible to plough by means of several yoke of oxen, the cost of the operation would be out of all proportion to the gain.

An ingenious substitute for ploughing, which I have myself seen put in practice upon a very rocky and hilly pasture in New Hampshire, is to turn out a herd of lean swine upon the land, and to scatter thinly about the pasture Indian corn enough to keep the animals growing indeed, but very hungry. Under these conditions, the hogs root up all the grass and eat it, roots, stems, and seeds; they clear the land of worms and insects, and the eggs of insects, and till and manure it pretty thoroughly in spite of stones and rocks, so that grass seeds scattered upon the surface of the ground after the swine have been removed find a very good opportunity to take root and to grow. It is no discredit to this really effective method of husbandry, that it seems to have been first suggested by Dean Swift, as a palpable absurdity.

Of course there are cases and places where the ploughing up of a pasture is the best method of renovating it, and it may often be possible to do this methodically, as was the custom in the old grass rotations of Europe. Even in this country, our ancestors occasionally came very near the doing of this thing. In lower New Hampshire at the beginning of this century there were farmers who ploughed up every year a part of their pasture land and seeded it down to rye. After the rye harvest they allowed sheep to run upon the stubble so that the land should be manured; but they made the mistake of leaving the land to itself, for grass and clover to come in naturally, as was the fashion in those days. It would probably have been better to sow grass seed with the rye, or, possibly, after the sheep, and so have made a methodical business of it. It is true, however, that for rough or poor land which is already in pasture the utility of ploughing is a very questionable matter, unless indeed the grass is pretty thoroughly run out. Generally speaking, the ploughing of any pasture which is still in fairly good condition is deprecated both by those farmers who have have had most experience with pastures, and by the residents of old countries where pastures have long been kept up.

It should be said, in parenthesis, that comparatively few Americans really know much about the maintenance of pastures. We have few traditions on the subject and very little experience. It is but a very few years, comparatively speaking, since the question of improving pastures has been much discussed in this country; and, it would appear that the first idea that came into men's minds was to plough, cultivate, and lay down to grass; then mow two or three years for hay, and finally revert to pasture. But, as the years roll on, the European opinion that it is unwise ever to plough land that is to be used for pasturage gains strength in some of our grazing regions.

Richness of old Pastures.

It is said that the grass of the old European pastures that have never been ploughed starts earlier in the season than that of newly made pastures; that it endures later in the autumn, and that the milk from such pastures is richer, that is to say less watery, than that from land which has been reseeded. This last item ceases, of course, to be one of advantage to the milkman who wishes to sell milk as milk. But if the intention is to make butter or cheese, there is an advantage in the milk from old pastures, since a smaller number of quarts of such milk will make a given amount of butter or of cheese. One computation has been published, to the effect that ten quarts of old-pasture milk will make a pound of butter, while as many as thirteen quarts are required to that end when the milk is obtained from pastures that have been recently laid down.

One reason of the poverty of new-made pastures in this country appears to be that, in seeding down land to grass, we neither use the kinds of seeds that are best fitted for pastures, nor sow a sufficient variety of grasses. Timothy, red-top, and red clover may possibly be the best mixture for the majority of our mowing-fields; but it is very certain that these grasses, excepting red-top, are not well adapted for pastures. As was just now said, there is needed in pastures a great variety of grasses, some to come early and others late, and others between times; some to grow in spite of drought, and others to prosper best in rainy weather; each kind to grow in the spaces between the rest, and to feed upon what the others leave. One thing is true, at all events, viz. that it is not easy by artificial means quickly to produce such sward as is seen in good old pastures. It could be done in time, perhaps, by laying down the land as for a lawn, and then cropping the grass continually with a lawn-mower, as a preliminary to the admission of cattle. But with what difficulty, and at what a cost!

Many farmers try to keep down their bush pastures by going through them in August with a short scythe, the so-called bush-scythe, and subsequently burning the dry brush upon the stumps of the bushes. This is a very inefficient method, unless, indeed, the bushes are juniper or some other resinous shrub, in which event the bush-hook, or even a hatchet, axe, or bill-hook, would naturally replace the scythe. Chemically considered, the process of bush-mowing would have a certain merit, if labor were cheap enough to permit of the bushes being mown or lopped when young, and saved, to be used as sheep fodder in winter, or for making manure. As now conducted, the process is wasteful, and not particularly effective. Hardwood bushes are seldom killed by such burning, while it often happens that a good deal of the grass around them is killed. Indeed, the bushes would probably suffer more than they do now, if the cuttings were immediately raked away, so that cattle could come at the stumps and gnaw off the young sprouts at the first moment of their appearance. The true way of killing such sprouts is to overstock the pasture with sheep, so that every green thing within the enclosure shall be eaten off close, and this method is in fact employed not infrequently in New England, as will be explained directly.

In case there are but few bushes in a pasture, farmers often pull them up by the roots by means of a hook worked with a yoke of oxen, or two men work together, one to bend down the bush, while the other cuts off its roots with a stub hoe. They then drag a harrow over the torn places, and scatter white-clover seed, or the sweepings of their barns. White clover is specially esteemed for this purpose, both because it does well in pastures and is liked by all kinds of cattle, and because a single plant will spread over a large surface, to the exclusion of weeds and spindling grasses. Because of this spreading habit of growth, only a very small quantity of the white-clover seed is needed for an acre of land. Some farmers sow a little rye with the grass seed on the spots to be renovated, and let the cattle feed upon it from the first moment of its appearance. When continually headed in by the biting of animals, rye will continue to throw out leaves for a long while.

Rib-Ploughing for renovating Pastures.

Attention has already been called in Volume I. to the possibility of applying the old English method of rib-ploughing for the improvement of pastures which have run out. In ribbing, the plough simply turns over a thin slice of sod, and consequently requires no great expenditure of labor. Not every sod need be turned, but only every other sod in such manner that the turned sod shall fall face to face upon grass which has not been disturbed. Grass seeds, clover seeds, and rye might be sown immediately upon the ribs or ridges, leaving the surface of the field uneven. By proceeding in this way upon sandy pastures and those free from stumps and stones, it would be possible to destroy the old grasses and weeds, especially white-top, and to take a new start, at the least possible cost of labor.

Some farmers have found an advantage in top-dressing their pastures with plaster of Paris, and in regions where plaster is an effective manure this method is undoubtedly a good one. Others find their advantage in top-dressing with wood ashes, or with leached ashes. Others top-dress with composts of one kind or another, especially the bare spots, or those where the grass is poor; then they harrow and scatter grass seed, which they brush in or roll in when practicable. Sometimes they do not even harrow the land, for fear of injuring the grasses that are already there, but simply spread the manure thinly, and then scatter the seed upon it and the turf.

Sheep for renovating Pastures.

All these devices are good, but perhaps the best general method of all is to overstock the pasture with sheep, as was said, no matter whether the land has run out or run wild. One plan is to have a movable fence, so that small portions of the land can be partitioned off, and to keep the sheep upon these plots until they have eaten up everything, after which the land is harrowed, if possible, and sown with grass seed or with clover. Another plan is to keep rather more sheep in a pasture than it can carry, during several years. In either event the sheep must receive a sufficient supply of some concentrated food, such as oil-cake or grain, to make up the deficiency of the pasture, and to keep them in proper condition. The rich food has the merit meanwhile that it manures the land.

Much good may be done to many pastures by sheep, even when there is no intention of employing an excess of them, since they are fond of many plants that neat cattle do not care for, and indeed eat with avidity and impunity many weeds which cattle dislike and avoid, notably buttercups, cowslips, and white-weed. A very few sheep, kept in a pasture that is fairly well stocked with cows, will do much towards keeping down plants whose presence is undesirable. The sheep prune the pasture, as it were, and clear it up. But it is not well to have too many sheep graze together with cattle, since, from feeding so much closer than the cattle, they are able to pick out the finest of the young grasses and clovers, and so consume the very best part of the food. Instead of a few sheep kept constantly, a flock of sheep may once in a while be turned into pastures that have been eaten close by neat cattle. Or, instead of that, the pasturing of cows may be made to alternate year by year, or two years by two years, with the pasturing of sheep; the sheep not to be in excess in these cases, but to be supported entirely by the pasture grass. The idea here is, simply, that the sheep will check much vegetation that cows do not like, and will meanwhile fertilize the soil by their droppings, which, unlike those of horned cattle, are evenly distributed.

There are cases on record where fields that were full of white-weed or buttercups have have been completely cleared by pasturing the fields with sheep, not in excess, for a couple of years, from early spring to the last of June. Under this treatment few if any of the weeds ever came to flower, and they could not withstand two years of such close feeding. So too, with rag-weed and the annual grasses that flower in late summer; sheep will eat them readily when not yet ripe, and thus prevent them from flourishing and going to seed.

It might often be good policy for the farmer to keep a few sheep merely as instruments for the clearing of pastures in this way, and for consuming weeds collected from gardens and tilled fields. The idea would be to let the sheep feed in the pastures in alternation with the cows. Much good fodder might be utilized by means of them, and a vast number of weeds and of seeds of weeds be destroyed. Sheep are specially well adapted for pasturing orchards. They manure the land evenly, and by eating windfall fruit they destroy the grubs which have caused the fruit to drop. If left unmolested, these grubs would bury themselves in the ground and change to moths, in due season, for stinging the fruit of the next year. If the land beneath mature apple trees, for example, were laid down to orchard grass and stocked with sheep, the trees would probably bear much more and better fruit than can be got from them by the usual method of treatment. If occasional tillage should be deemed necessary, it might be had by tearing the sod with a scarifier, or by passing beneath it some kind of a shallow subsoil plough.

Instead of changing from one kind of cattle to another from year to year, it might possibly be well in some cases, where the land is strong and smooth, to mow the pasture once in a term of years, as if it were a hay-field, in the case of a favorable season. And this in spite of the risk, illustrated by Darwin, that the growing crop might smother some good grasses that thrive in cropped pastures. Mowing in this way might perhaps tend to favor the growth of grasses that seed very early and very late, and perhaps check those that ripen at the time of mowing. Many weeds peculiar to pastures would be checked by the mowing, while others peculiar to mowing-fields would start up, and would be eaten down in the autumn, or after the hay harvest, when the cattle were returned to the field. One advantage incidental to the mowing would be the opportunity to view the grasses in the field, and to note what kinds were predominant.

Use of "Followers" in Pastures.

In many places it is the custom to change the animals from one pasture to another, in such wise that there shall always be one field in good case for the milch cows or fatting cattle. After these more important animals have eaten the grass tolerably close, they are changed to a field that has been at rest, and young cattle are turned into the field which the cows have left, and finally sheep may succeed the young cattle.

This idea of "followers" in pastures is an old idea, and it is an excellent one. In many districts in England it is customary to buy lean Scotch cattle in autumn to clear up the pastures at the time when the heavier cattle are turned into the aftermath of the mowing fields. A somewhat similar practice prevails in Eastern Massachusetts, in years when the summer has been moist enough to keep up a good supply of grass. Store cattle are brought in September and turned into the pastures and stubble and mowing fields, where they not only put much good grass to profit, and vast numbers of weeds also, but, after the frosty nights have come, they consume great quantities of grass that had previously been unpalatable to stock.

Whenever there are not enough animals kept in a pasture to eat off the herbage close, many tufts of grass will grow rank and tall, especially where dung or urine has fallen, and much grass may even go to seed. All such tall grass is avoided by cattle until the advent of frosty nights. But after it has been touched by frost, the rank grass is sweetened, as the saying is, and then animals will eat it readily. The practices above mentioned depend not only on the immediate economy of putting all available herbage to use, but in part doubtless upon an old belief of English graziers, that it is good for a pasture to be eaten off very close not infrequently, and particularly in early summer. There is little reason to doubt the correctness of this view, since the close feeding would tend to the production of a fine, close, even turf, such as all experience teaches is excellent for cattle, while it would prevent any tufts of grass from growing up tall and becoming unpalatable. Nevertheless, the pasture must not be overstocked nor grazed too closely, particularly not for any long period. Leaves enough must be allowed to grow to feed the roots.

The changes brought about in natural grass-lands by the treading, grazing, and manuring of cattle, whenever such lands are first devoted to pasturage, has often been noticed in this country. Mr. Darwin has spoken of the matter in the following terms. In crossing the pampas towards Buenos Ayres he was much struck with the marked change in the aspect of the country after passing the river Salado. From a coarse herbage on one side of the river, the travellers came to a carpet of fine green verdure on the other. Darwin was at first disposed to attribute these appearances to some changes in the nature of the soil, but the inhabitants assured him that the change was wholly due to the manuring and grazing of cattle. He noticed the same appearances in other localities, and remarks that exactly the same fact has been observed in the prairies of North America, where coarse grass between five and six feet high, when grazed by cattle, changes into common pasture land.

The matter is manifestly closely related to the "bringing in" of one or another kind of grass by means of special fertilizers; though in that case it might be said that favoring influences promote the overpowering growth of certain species, while in the case of grazing cattle the grass is subjected to such molestations and long suffering as work to exclude many of the less robust varieties.

A few horses or colts kept in pasture together with or after cattle, would do good in the same sense that sheep do good by eating various kinds of plants which horned cattle pass by. Herds of horses are inferior to flocks of sheep, in that the horse does not feed evenly or fairly as the term is. But a few horses running in a large cattle pasture will keep down the rank growth of grass where the manure of the cattle has been dropped, and they will graze too where cattle have trampled the grass. In general, it may be said that any pasture which is made to carry a mixed stock of cattle, sheep, and horses will be more evenly grazed than if only one kind of animal has been kept in it.

As has been said already, some part of the popular objection to horses in pastures is clearly a tradition from the times when horses were used for carting goods in England. They were pastured by night, and kept at work on the roads by day, where most of their dung was dropped. Hence they took more matter from the fields than they returned to them, and tended to exhaust the fields.

So far as the chemistry of the subject is concerned, there can be no doubt that pasturage can be more thoroughly utilized, and the fields kept in better condition, by a mixture of several kinds of animals than by any one single kind; for not only will the different species of animals eat different kinds of grasses and weeds, and eat any one kind at different stages of its development, but there is furthermore the very important consideration, that, while each species of animal dislikes to feed near its own dung, it has few if any scruples about feeding near the dung of the other animals. When we consider how much excellent grass in every pasture devoted solely to neat stock is thrown out of the account, in so far as such stock is concerned, by the droppings of the animals, the importance of adding sheep or colts enough to subsist upon this spoiled grass is manifest.

Mixed Stock apt to injure one another.

There would be no question whatsoever as to the superior economy of mixed stock in pastures, if it were possible to make sure that the animals would not injure or annoy one another, and that the droppings of one kind would not be detrimental to the health of the rest. Sheep and young cattle, but not calves, are said to do well together, but neither cattle nor horses do well with sheep as a rule. One or two cosset sheep that have been reared among cows will prosper among them. But flocks of sheep and herds of cattle represent different interests. A few cattle that have been reared among sheep, and always kept with them, are said to be a valuable means of protecting sheep from dogs. The cattle attack the dogs and drive them from the field. A cosset goat would probably do this work still better. Horses and cows are apt to annoy each other, and seriously to injure one another for that matter, when kept in the same pasture; especially when there is but one animal of one kind against several individuals of the other kind.

Since so much has been learned of late years about the genesis of the internal parasites of animals, how many of them lurk in one animal before they come to another, and how they pass through various stages and transformations, each of which may occur in a different kind of animal, it behooves the farmer to take care how he mixes different kinds of stock in the pasture, lest he promote the growth of these parasites, and their transfer from one animal to another. Cases are on record, for example, of calves having been made sick, some of them unto death, by parasites derived from the dung of hogs with which the calves were pastured.

Rough and ready methods of irrigation, and of drainage also, such as dead furrows, and even land beds, may often be applied with advantage to pasture land. It is impossible that there should be a good growth of nutritious grasses where stagnant water rests in or upon the soil.

Distribution of the Manure in Pastures.

With regard to the droppings of neat cattle, that is to say, the dried clots of dung, it is a question how much, if anything, can be done with economy in this country towards scattering them upon the surface of the land. The urine of cattle at pasture is well disposed of. It sinks at once into the earth, and is probably distributed there as well as it possibly could be. But with the dung of large cattle it is a very different matter. When left as dropped, some plants are killed by it altogether, while the adjacent grass shoots up rank and coarse, and is notoriously unpalatable to cattle, unless it be mown and wilted, or unless it has been touched by frost.

If the dung could only be spread or scattered, no grass would be killed, and none would be made unduly rank, while the general fertility of the field would be increased. The question to be solved is, simply, Will spreading the dung pay? Probably it would pay in some exceptional cases; but probably it would not pay at all as the general rule. The English, for their park pastures and for lawns that are pastured, have what they call a chain-harrow, which goes over the surface of the ground lightly, scattering all clots of dung, all mole-hills and ant-hills, and raking up moss, and airing the sod generally without tearing it. It may be worked with a single horse, and is an inexpensive and efficient instrument that greatly commends itself, excepting a certain liability to kink, though it is probably too much of a refinement to be in place upon cheap land. Perhaps a well worn Thomas smoothing-harrow might serve fairly well as a substitute for the chain-harrow.

It is a curious reflection, that, while in Europe the farmers argue that pasture land that is kept stocked with cattle rather tends to improve than to run out, farmers in New England regard the pasturing of stock as an exhaustive process. It has been said again and again at meetings of our agricultural societies, that the pastures have deteriorated because we have been taking away from them continually without putting anything back. This statement is clearly wrong, because too general and too emphatic. What has been taken away from the pastures is, in most cases, almost as nothing in comparison with what has been put back again in the dung and urine of the animals. Some nitrogen has been removed, of course, in the form of wool, and milk, and flesh; and small amounts of ash ingredients also, in the wool of sheep, the milk of cows, and the bone and flesh of growing animals; but all these ash ingredients could assuredly have been made good by the yearly disintegration of the stones and gravel in the pasture earth. In some cases, it is true, the source of waste has been more serious, as when the pastured cattle are driven home at night and kept up in the barn or yard until morning; in which event the pasture is necessarily deprived of what dung has been dropped by the animals during their absence from it.

But it is not such pastures as these alone that are seen specially to fail, any more than those in which the cattle are left undisturbed night and day through the summer; and the causes of the deterioration must be explained in some other way than by the theory of chemical exhaustion. Indeed, it is evident enough that the coming in of bushes and of bad grasses is a more serious difficulty in most cases than the lack of plant-food; and it is evident, also, that droughts are very hurtful, because the good grasses suffer more during dry weather than the bad. It is certain that, if a proper supply of moisture could be insured throughout the growing season, it would be easy to bring in good grasses and to maintain them.

It is a tenet of European husbandry, that, on breaking up land which has long been in pasture, there will be no need of manuring for the first set of crops that are to be taken; and a somewhat similar idea prevails in New England, in spite of all the talk which is uttered concerning the exhaustion of the pastures. It is a common practice abroad to lime such land on ploughing it, and the practice might sometimes be copied here with advantage.

Some part of the deterioration of American pastures may be due to the improper distribution of the dung and urine which are dropped upon such great wastes of land. It may be well sometimes, on this account, to fence off a favorite standing-place on purpose to exclude the cattle from it. Conversely, it may be practicable to induce the animals to loiter on a patch of inferior land, by keeping a salt-box there, or by feeding out a little meal there daily. In the same sense, it may often be best to have shade trees stand on the poorer parts of a pasture, rather than upon the richer land; though it should be said there are some farmers who maintain that shade trees should be excluded from pastures altogether, because animals are apt to fall into the habit of spending much time in lying or loitering beneath them instead of attending constantly to their proper business of eating grass.

In cases where water has to be brought to pastures in aqueducts, it will often be practicable to place the troughs on some knoll of poor thirsty soil, where both the drippings from the troughs and the droppings of the animals would do good service. Yet again, the grass that grows rank and tall in the spring on spots which are much resorted to by cattle, and which is in consequence rejected by them, may sometimes be mown with advantage in June, and made into hay. By so doing, a quantity of useful winter forage is gained, while the new growth of grass will commonly be freely eaten by the animals, and the place will continue to afford them good pasturage thenceforth.

Pastures injured by Insects.

A much more important matter than the scattering of the manure is the destruction of insects in pasture lands. It often happens that grasshoppers and crickets abound in dry pastures, and destroy an amount of herbage of which few people have any just conception. By chance one day, as I sat reading at a closed window, I had an opportunity to see a grasshopper of moderate size attack a lilac leaf upon a bush outside the house. The leaf was fully grown, and there was no evidence either that the insect was specially hungry or in haste, yet he disposed of the entire leaf in an incredibly short space of time. Several mechanical devices of apparent merit, to be worked by horse power, have been invented of late years for sweeping up grasshoppers by the bushel from mowing fields and pastures. Some of them were described in the United States Agricultural Report for 1883.

Guinea hens, and turkeys also, are effective agents, and may be applied methodically for abating these pests. At the Paris Exposition of 1867 there was exhibited a simple contrivance for applying the turkey cure. A high rectangular framework, set upon wagon wheels, and covered with white cotton cloth constituted the house and home of the birds. Perhaps an ordinary hay rigging, covered with hay caps, would answer a similar purpose. The idea was, that a flock of turkeys should be kept in this movable pen. That it should be their home and roosting-place always. After they had become wonted to this "house" they could be transported in it, or driven before it to any field specially beset with grasshoppers, and left there until the field was cleared. The white, tent-like structure was visible to the birds from afar, and they were accustomed to rally upon it, no matter in what field it might be placed. Pea-hens are equally efficient with turkeys, or even more so, but ordinary hens are less serviceable, because less enterprising and less fond of roaming in strange places.

Naturally enough, the foregoing remarks do not apply to cases where flights of grasshoppers or locusts bring enormous numbers of these insects to the fields. Indeed, it has been said of such conditions in California, that turkeys are apt to die after they have eaten to excess of grasshoppers, — perhaps because of irritations or stoppages caused by the rough and indigestible legs and wing-cases of the insects.

Another insect that does much harm to lawns and to old dry mowing-fields is the white grub of the June beetle, which, while in the maggot state, lives underground for three years, and subsists upon the roots of grasses and other plants. The presence of this pest is indicated not only by the manifest sufferings of the grass plants, but often by little pits upon the land which are dug by skunks that feed upon the grub.

It might, perhaps, sometimes be possible and advantageous to destroy the grub by applying some soluble corrosive fertilizer — such, for example, as a high grade superphosphate, or the acid sulphate of potash — to those patches upon the field which are known to be beset with the grubs. Possibly the grub might be smothered or drawn out from the land by some system of mulching the bad spots heavily, as with tan bark or compost. In any event, the treated patches would have to be reseeded after the destruction of the grub.

One important means of caring for pastures is the just apportionment of cattle to the area of the field, or rather to the amount of grass. Except in the case of reclaiming a pasture which has run wild, or the occasional clearing up of a pasture, as has been said, care should be taken not to overstock the land to any such extent that the good grass will be gnawed down to the very roots, or the roots torn up. On the other hand, there should not be too few cattle, since they would feed only upon special patches, and leave the remainder of the field to run up to bushes, weeds, or bad grasses. On really good pastures an acre of land will support a cow; but in many places in New England six acres will hardly suffice, while on some of the arid pasture lands at the West fifteen to twenty acres are allowed for each animal.

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